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NASA WORKSHOP ON SOLAR-TERRESTRIAL STUDIES FROM A MANNED SPACE STATION

The summary papers from a NASA Workshop
conducted February 14-16, 1977, at the
Utah State University, Logan, Utah

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FOREWORD

This report collects the primary results from a Workshop on Solar-Terrestrial Studies from a Manned Space Station held February 14-16, 1977, at the Utah State University, Logan, Utah. The Workshop examined the utility of coordinated instrument ensembles having a scale and complexity not accommodated practically on automated spacecraft. The appropriate duration for operation of these ensembles is long in order to address the difficult but vitally important questions concerning the mechanisms of solar influence on the environment in which man lives.

The initial concepts from which the Workshop began its deliberations are embodied in the NASA document, "The Solar-Terrestrial Observatory as a Major Module of a Space Station: An Advocacy Document," George C. Marshall Space Flight Center, September 1, 1976 (see Appendix C). More broadly, the problems to be addressed are highlighted in the NASA Outlook for Space.

The specific purpose of the Workshop was to bring together specialists in the areas of solar physics, atmospheric physics, magnetospheric physics, and Sun-weather relationships in order to stimulate interdisciplinary discussions about the intertwined cause and effect relationships within the Sun-Earth system. Further, these discussions were expected to expose typical instrumentation requirements for exploring and ultimately exploiting these relationships.

It is hoped that this collection will propagate further development of more comprehensive, elaborate, and refined definition of the needs and uses for a Solar-Terrestrial Observatory in such a manner as to make it a significant factor in the proper management and use of the Earth's limited resources.

The Workshop was organized by Drs. Donald J. Williams (Chairman) of the Space Environment Laboratory, NOAA, and Charles R. Chappell of the Space Sciences Laboratory. Marshall Space Flight Center, NASA. Professors Andrew F. Nagy and Peter M. Banks, Physics Department, Utah State University, were hosts.

INTRODUCTION

The field of solar-terrestrial physics is not new; the early part of this century saw the pioneering work of Birkeland and Störmer on aurorae and of Lindeman, Chapman, Bartels, and others on geomagnetic storms. In more recent years, possible solar-weather relationships have been reinvestigated, and there seems to be a growing, albeit far from unanimous, feeling that climatic trends as well as shorter term weather changes may be better understood through coordinated studies of the terrestrial environment as influenced by the Sun.

This environment extends from the dense troposphere at sea level through the tenuous magnetosphere reaching a hundred thousand kilometers into space. The study of the coupling between components of the solar-terrestrial system may lead ultimately to an understanding upon which to base decisions that men must make concerning interactions with their environment. This study can also lay the foundation for the long-term prediction of environmental changes which can have significant economic and social benefits.

The advanced state of our technology has placed us in a position from which the study of the solar-terrestrial environment can be undertaken in an ever more comprehensive manner. Beginning with Skylab, scientists were able to carry out coordinated, multi-instrument observations of the Sun, with the on-board scientist-astronaut able to key the observations to transient solar events. Working with a ground-based science team, the astronauts were able to identify and conduct detailed studies of solar phenomena that were previously unrecognized. The fruits of the Skylab mission are still being harvested as new knowledge continues to flow from the data taken during the missions.

The capabilities developed in Skylab will be broadened in the Space Shuttle era. Manned operation of experiments will continue and will be enhanced by the reusability of instruments. The sortie mode of Shuttle operation will allow the serial development of even more powerful instrument techniques which can be combined in different configurations and reflown on subsequent Shuttle missions. Skylab has given us the experience of manned observation tailored to specific transient events, an ingredient which is necessary to tackle the complex solar-terrestrial system. Shuttle and Spacelab will give us an inventory of advanced flight-proven instrumentation which can be directly applied to the long-duration observation of the Sun-Earth environment.

Having as background the Skylab experience and a knowledge of the instrument developments being planned for the Shuttle era, a group of scientists in the disciplines of solar physics, magnetospheric physics, atmospheric physics, and Sun-weather relationships assembled at Utah State University in February 1977 to discuss the potential for coordinated solar-terrestrial observations from one or more manned space stations. In these discussions, the assembly of instruments and support equipment deployed for this purpose was termed the Solar-Terrestrial Observatory or STO. Inevitably, such an

Observatory would be an evolving entity. It would be constituted first in low Earth orbit (sometimes abbreviated as LEO). Eventually, to achieve its full potential, the STO would be repositioned or reconstituted in geosynchronous Earth orbit (GEO). Initially, the STO would operate in a fact-finding, research mode; ultimately it would provide observational data for routine applications to the benefit of mankind.

The agenda for the Workshop is reproduced in Appendix A. After a series of introductory and background discussions, the group resolved into four subgroups: Solar Physics, Magnetospheric Physics, Atmospheric Physics, and Sun-Weather Relationships (Appendix B). These subgroups deliberated their respective aspects of the STO capability and then reported their conclusions for consideration by the full Workshop membership. Throughout this process, a vigorous interaction between subgroups was maintained. The subgroup summaries, duly revised to reflect discussion by the full Workshop, are reproduced in subsequent sections of this document.

The final section presents the collective conclusions of the Workshop, compiled from the discipline summaries and the remarks during the closing session. One overriding conclusion stands out: The synergistic interdisciplinary spirit achieved in the Workshop produced an initial concept of a Solar-Terrestrial Observatory promising a capability surprisingly beyond that previously anticipated by the participants. Further refinement and development of the concept is certainly demanded.

SOLAR PHYSICS

Background

Solar physics investigations have evolved to a state such that information in wavelengths and with techniques only possible from space platforms is crucial to the solution of most of the central problems in the discipline. In the recent past, observations from the OSO satellite series and Skylab have played major roles in the development of the field; and it is envisaged that the Solar Maximum Mission and Spacelab will likewise contribute substantially to future efforts.

Advantages of an STO

The Space Station will provide a unique opportunity for solar physics, for it is only from such a platform that studies of the evolution of solar phenomena over long periods can be attempted. Then it will be possible to mount programs of monitoring long-term variations in the solar output and state and employ the major solar facilities developed for Spacelab in the study of changes in the Sun over periods in excess of the Spacelab mission (a few weeks) duration. The Space Station offers unique capabilities for solar monitoring functions. It will be possible to include several experiments utilizing different techniques for solar constant, spectral irradiance, and cross-calibration purposes either on the station or a nearby tethered satellite (to avoid contamination problems) and to provide for absolute and relative calibration facilities on the Space Station itself. The correlation monitors will permit effective manned interface with the major solar instruments and with magnetospheric/atmospheric experiments requiring specific solar conditions before initiation. Such monitors are discussed in this section.

Program of Investigations

The solar physics instruments for a space station can be divided into two general categories: solar situation monitors and major solar instruments. The former category includes: instruments to measure the solar output (e.g., solar constant and solar spectral irradiance); correlation monitors providing on-board scientists with full-disk, modest spatial resolution information for the purposes of interplanetary and terrestrial correlations, selection of solar regions for study by the major instruments, and pointing guides; and instruments providing correlative measurements (e.g., cross calibration with free-flying satellite experiments). The category of major instruments includes the more powerful state-of-the-art instruments designed with specific investigative tasks in mind. Such instrumentation may be applied to the solution of problems in solar physics whose relevance to specific solar-terrestrial problems is not entirely clear at the time. These instruments will provide the major observational inputs to the fundamental study of the Sun itself.

Solar experiments in the category of solar situation monitors include those which are of direct, fundamental relevance to the specification of the solar input to the terrestrial environment; foremost in this area are instruments to measure the solar constant and the solar spectral irradiance. It is now recognized that the determination of the total solar flux with high accuracy over a long time period — several solar cycles — is required to assess its influence on the terrestrial climate. Further, it is generally accepted that such measurements must have high accuracy (better than 0.1 percent, or some five times better than that achieved before) if they are to serve as useful inputs to models of climatic variation. At that level of accuracy, the variation of solar flux due to the presence of sunspots is measurable and must be considered. These accuracies will require continued calibration which can be carried out by the on-board science staff. Since the interaction of the solar flux with the terrestrial atmosphere is a sensitive function of wavelength and is a maximum in the ultraviolet, it is also necessary to measure the solar spectral irradiance. The precise specification of the accuracies and spectral resolutions required must await detailed study, but generally it is anticipated that the principal wavelength region of interest is that of 2000-3500 Å, where stratospheric photochemistry is largely influenced; measurements of 1 to 2 percent accuracy are required in this spectral region. Shorter wavelengths, of importance higher in the atmosphere, require somewhat less accuracy, approximately 10 percent. Also, monitoring of the infrared solar flux to high accuracy may be important.

Another subcategory of measurements required includes instruments capable of monitoring the state of the solar disk. Included are modest spatial resolution instruments (2-5 arc sec) capable of specification of the solar state for (a) the terrestrial input, (b) selection of areas of interest for more detailed study (e.g., regions of emerging magnetic flux), and (c) determination of pointing requirements for the major solar instruments. These instruments will provide the real-time information upon which on-board scientists can base their tailored observations of the coupled solar-terrestrial system. For example, X-ray or XUV images of the solar disk may provide knowledge of the presence of coronal holes in anticipation of relevant magnetospheric measurements days later. Observations of the solar disk with a tuneable visible light filter ($H\alpha$, H_e 10830 Å, etc.), with a magnetograph, or with an EUV monitor would permit selection of areas for intensive study or instrument pointing information. The X-ray and ultraviolet instruments, together with a white light coronagraph, would allow determination of the global characteristics of the chromosphere, transition region, and lower and outer corona for later correlation with solar and terrestrial results. Finally, this category of correlation monitors includes detectors of hard X-ray flux ($\leq$ 500 keV), and possibly 10-cm wavelength flux, for the presence of impulsive solar events.

There remains in the category of solar monitors instruments capable of providing cross calibration with free-flying satellites; for example, calibration of results from such satellites as Solrad-High and GOES over extended periods through the simultaneous observation of solar events from the Space Station and the free-flyer.

In the following, we outline two general, yet directed, problems in solar physics which may be investigated from a space station in the period post-1985. The problems discussed are not necessarily intended to represent the most important problems of solar physics in that era; but, on the other hand, they represent questions of sufficient magnitude to be of substantial general interest in solar (and solar-terrestrial) physics at that time. It should be noted that questions of central importance in other areas — the physics of solar flares, for example — will certainly be present in the era of the Space Station. However, because of the major observational effort to be directed toward understanding the flare problem during the Solar Maximum Mission and possibly its follow-on mission in the early 1980's, it is even more difficult to conjecture what specific problems will remain in flare physics than to predict the problems in the areas discussed in the following paragraphs.

Creation and Evolution of Solar Magnetism. The Sun is a magnetic variable star. In fact, the variability associated with solar magnetism is of dominant importance on Earth and throughout the solar system. The understanding of this cyclical phenomenon is a profound intellectual challenge that has eluded mankind since the discovery of the sunspot cycle. It is only recently, however, that the immense practical importance of this knowledge has begun to be appreciated.

The study of solar magnetism must encompass the emergence of new magnetic flux through the solar photosphere, the re-ordering of this flux into large-scale magnetic structures, and the extension of a portion of these magnetic fields into interplanetary space.

The majority of the solar magnetic field emerges in the form of sub arc-second flux ropes. The study of the formation and evolution of these small elements requires extended observations of the highest quality. Magnetographic (all Stokes' parameters) and velocity field measurements are required at photospheric and chromospheric levels with a meter-class optical telescope with appropriate focal plane instrumentation. Observation of the extension of these fields to higher levels where the role of magnetic energy and thermal energy may be altered will require XUV and soft X-ray spectroheliographs with high spatial resolution.

There is good reason to believe that strong electric current systems develop in the course of the emergence and development of the magnetic fields. The restructuring of the fields associated with the dissipation of these currents and the reconnection of the fields into states of lower potential energy is accompanied by solar flares and the other dynamic processes associated with the life cycle of solar active regions. There is little hope of ever being able to trace these processes on the basis of Earth-based observations. Unbroken sequences of diffraction-limited operation are crucial, and concomitant observations at visible, XUV, and soft X-ray wavelengths are absolutely necessary.

As the magnetic field evolves over periods of days to weeks, we know that very large, ordered structures are formed. The present understanding of this process is inadequate. It is of utmost importance to achieve the best possible observational description of the coronal field topology as a function of time. This will require, in addition to the instruments mentioned previously, a white light coronagraph and a coronal emission line polarimeter. Technically more challenging is the task of measuring coronal field strengths.

The fundamental question of the nature of the solar cycle requires observational and theoretical study. Descriptive models based on flux diffusion under the influence of velocity fields, identified with chromospheric supergranulation cells, have been successful in reproducing some of the features of the solar cycle. However, improved observations of both the ordered and stochastic components of the velocity field with extended time sequences of the trajectory of individual magnetic flux elements in the photosphere, obtainable only from space-borne instruments, should shed considerable light on the subsurface convective forces which actually may drive this process. The instrumentation requirements are clear and technically feasible and the observational requirements definite. Furthermore, the theoretical tools necessary to understand and be tested by the observations are under development.

Mass Loss from the Sun. The great extent of the outer solar atmosphere, the corona, is a consequence of the high temperature of the gas. Furthermore, direct in situ observations have established that at the orbit of the Earth there is a continuous but strongly variable flow of plasma from the Sun — the solar wind. This mass loss is of fundamental astrophysical interest, and the details of the interaction of the magnetized plasma with the Earth and its magnetosphere are of major scientific and practical interest.

Progress to date toward an understanding of the origin, acceleration, and evolution of this mass flow has resulted from combined solar and interplanetary observations coupled with theoretical modeling of the processes involved. An adequate physical description has yet to be formulated, although a close relationship between the properties of this mass flow and solar magnetism is established.

The desired fundamental understanding of the various aspects of this mass flow will require improved observations of the coronal mass and temperature distributions and their evolution in time. Crucial observations of the outwardly moving mass in the low corona can be obtained through Doppler shift observations with sensitive XUV spectrometers. High spatial resolution white light and Lyman alpha coronagraphs can provide information on temperature and velocity of outer coronal material. It is further necessary to specify the coronal magnetic field geometry as well as conditions at the base of the corona through the use of the optical and X-ray instruments mentioned earlier in the discussion of solar magnetism.

At some level the physical state of the extended solar corona changes from domination by thermal and magnetic energy densities to domination by the momentum of the flow itself. Also, the importance of observed wave and transient effects on the flow are poorly understood. Both radio and in situ particle and field measurements will help to address these aspects of the problem.

The assimilation of the many previously mentioned observations into a comprehensive theoretical description is a reasonable goal. A key element to the success of this study would be the detailed and comprehensive coverage from a solar-terrestrial observatory module on a permanent space station.

Finally, there are two other important aspects of the future space station to consider. The first aspect concerns the use of man. Considerable expertise has been developed concerning the automation of sequences of observations, and by 1985 further experience in this field will have been acquired by a successful completion of the Solar Maximum Mission. Nevertheless, we foresee that some of the monitor-type experiments and, to an even larger degree, most of the research-type experiments will not be executed with the required performance to solve the problem in question without the intervention of a trained observer in the Space Station. The painstaking calibration and measurement accuracy needed for the solar-irradiance determination and the high pointing accuracy required for the small-scale magnetic-field observations are but two examples that indicate the necessity for manned intervention in well-planned observing sequences. With the sophisticated instrumentation we have proposed, other needs are highly likely to occur. These needs may include repair activities or the flexibility for observing complex phenomena — examples in which the Skylab experience demonstrated the desirability of man's presence.

The second additional aspect concerns the possible orbits of the future Space Station. A GEO permits nearly continuous observation of the Sun, whereas a LEO involves an approximately 30-min interruption of sunlight during every 1.5-hour cycle. Thus, for example, a GEO is highly desirable in order to track the detailed evolution of solar phenomena for time intervals exceeding an hour.

On the other hand, high-energy detectors may require special shielding to protect them from the relatively hostile space environment at the altitude of 6.6 Earth radii.

MAGNETOSPHERIC PHYSICS

Background

From the discussions during the Workshop, it is clear that the space station concept opens the way to an exciting new era of magnetospheric science. The progression of platforms from Spacelab to the LEO Space Station and the GEO Space Station represents a dramatic increase in scientific utility for the key problems of space plasma physics, magnetospheric particle dynamics, and magnetosphere-ionosphere-atmosphere (MIA) coupling.

From our preliminary studies, it appears that the LEO station and the GEO station will benefit greatly from the developments of the Spacelab program. In particular, the opportunity to understand and exploit the full capabilities of scientists-in-orbit in Spacelab should prove to be an important accomplishment. Nevertheless, a number of features of the space station concept provide compelling arguments suggesting that it should be the next step after Spacelab.

Advantages of an STO

For both the LEO and GEO stations, the long-duration observing periods (up to 6 months) should substantially improve prospects for detecting and understanding transient magnetospheric events. The links in a possible chain of cause and effect involved with solar-terrestrial interactions may well be observable only with such an extended mission. In addition, the large payload weight, volume, and power of a space station make it an ideal platform for conducting extensive remote sensing and active perturbation investigations of the various phenomena involved with the coupling of mass, energy, and momentum in the MIA system. Both the LEO and GEO stations would incorporate the capability to deploy clusters of specialized sensors needed to separate spatial and temporal aspects of the space plasma environment.

It is with GEO, however, that one finds the best opportunity to conduct important new studies relevant to magnetospheric-ionospheric-atmospheric science. As outlined in succeeding paragraphs, the ability to remain nearly fixed on a particular magnetic field line has great importance for a number of outstanding scientific experiments, including the active study of wave-particle interactions, the transmission of charged particle beams through the magnetosphere, and the active radiowave probing of the magnetopause and plasmapause. Since GEO would lie outside the plasmasphere much of the time, it also provides an ideal platform for studying plasmasphere dynamics through active and passive experiments.

Most experiments in magnetospheric physics will require the on-board scientist for their operation. In particular, the so-called "active" experiments in which perturbations are introduced into the magnetosphere require man's pattern recognition and decision-making capability. The scientist will observe the progress of these experiments and modify the operations according to the real-time results.

Program of Investigations

Electric Fields and Currents. Energy and momentum is transferred from the solar wind to the upper atmosphere by means of magnetic field-aligned currents which connect through the resistive high-latitude ionosphere. Both atmospheric Joule heating and a widespread pattern of global electric field are direct consequences of these currents. Furthermore, there seems to be a direct connection between the field-aligned currents and the acceleration of charged particles producing auroras. This last problem is particularly worthy of study since numerous observations suggest that auroras are an indication of a violation of the basic assumption of classical magnetohydrodynamics; i.e., that in the low-density plasma of space, the magnetic field lines are equipotentials.

Both the LEO and GEO stations offer dramatic new opportunities to probe the detailed electrical structure of space plasmas with a variety of techniques. Aboard the LEO station, experiments similar to those contemplated with Spacelab would be developed; i.e., remote imaging of ion tracers, the use of multiple remote probes, and the observation of electron beams. For the GEO station, a far more favorable situation exists since the rapid motion relative to magnetic field lines and the Earth's surface is largely absent. In this situation a charged particle accelerator can be used to full advantage to probe parallel and perpendicular electric fields. Coordinated ground observations, readily obtained for the long-duration GEO station, could accurately pinpoint particle beam atmospheric penetration, permitting study of particle reflections, beam drifts in the presence of perpendicular electric fields, and multi-echo dynamics. Using GEO station remote sensing instrumentation (low-light-level TV, X-ray imagers, and EUV), it may be possible to obtain the same information from the GEO station itself.

<u>Plasmasphere Dynamics</u>. A number of dynamical phenomena are associated with the plasmasphere, including the upward flow of thermoplasma from the ionosphere, the rapid convective drift of plasma in regions poleward

of the plasmapause, the formation of plasmapause red-arcs, and the upwelling of ionospheric plasma above the geomagnetic equator. During magnetic storms, the plasmasphere contracts violently, while afterwards it gradually expands poleward with great upflow of ionospheric plasma.

Much of our present information about the plasmasphere is derived from radio whistlers and in situ spacecraft probes. Neither technique can adequately describe the complex phenomena which seem to occur. Many new plasmasphere observations will be possible using new techniques especially suited to GEO.

From GEO, remote sensing of the plasmasphere will be possible using passive means based on 304A resonance fluorescence of He^+. Scanning of the plasmapause "limb" should provide a direct view of the spatial and temporal variation of magnetospheric electric fields at the plasmapause; i.e., information of crucial importance to understanding of substorm phenomena and the general interaction of the plasmasheet and the plasmapause. In addition, fluctuation of 304A EUV intensity within the plasmasphere can be used to deduce for the first time the distribution of thermoplasma along magnetic field lines near the magnetic equatorial plane, a region where strong hot-cold particle coupling is known to occur.

Another technique for probing the plasmapause is the coherent scatter radar, a device which relies upon the scattering properties of plasma density fluctuations viewed perpendicular to $\overline{B}$. Because of the close proximity of the ring current, sufficiently large density fluctuations may exist to permit remote detection and observation of not only the plasmapause itself, but also irregularity structures internal to the plasmasphere associated with radio whistler ducts. The same apparatus could also be used in an effort to detect and map the magnetopause throughout various periods of magnetospheric activity. In both cases, synchronous orbit provides an appropriately low density plasma in which radio-wave propagation is possible. Within the plasmasphere, such experiments could prove difficult.

A separate radio technique to probe the plasmasphere can be based on incoherent scatter radar stations at Arecibo, Jicamarca, and Millstone Hill. Using a forward-scatter mode, surface transmissions could be intercepted by an antenna/receiver aboard the GEO station. With appropriate apparatus, measurements of electron density, line-of-sight plasma drift velocity, and plasma temperature could be obtained throughout much of the plasmasphere.

At the plasmapause, both electron and proton precipitation into the upper atmosphere occurs as a consequence of wave-particle couplings. Remote GEO observation of the resulting optical, EUV, and X-ray emissions could provide important new information about the physical processes involved. For example, dynamical motions of the equatorial plasmapause are certain to be present, and a close analogy of the plasmapause-arc situation with auroral observations is present. It is well known that Defense Meteorological Satellite Program and International Satellite for Ionospheric Studies spacecraft observations have opened the way to broad, new understanding of auroral phenomena. Similarly, GEO observations of plasmapause-arcs (visual, EUV, and X-ray) should dramatically increase our awareness of new processes in this region.

Wave-Particle Coupling Studies. It is well known that wave-particle couplings account for a wide variety of important anomalous plasma processes. Very low frequency (VLF) radio waves, for example, have been shown to resonantly couple with energetic particles of the Earth's trapped radiation belts, leading to particle precipitation and radiation belt depletion. Various other plasma waves of higher frequency are thought to be of great importance to the stability of field-aligned currents, the stability of energetic particle beams, and the establishment of kilovolt electric potentials parallel to the geomagnetic field. Extensive studies of wave-particle coupling will be initiated with Spacelab, but, because of orbital and time requirements, important experiments will inevitably belong to the Space Station era.

The ability to deploy long antennas from LEO will lead to extensive experiments concerning the interaction of extremely low frequency (ELF) and VLF radio waves with trapped radiation belt particles. Because of the great power losses associated with ground-based experiments, space experiments should couple radio waves much more effectively to the trapped particles and provide dramatic new information about the interaction process; GEO, being near the region of maximal interaction, is especially important in this regard.

From GEO, the launching of other, higher frequency waves should prove valuable with respect to studies using artificially generated particles from a particle accelerator. Destabilization of particles injected into trapped orbits could be accomplished using radio waves with subsequent detection at the foot of the GEO magnetic field line. It is also noted that the operation of a sufficiently strong ELF/VLF transmitter at GEO could lead to a substantial decrease in the local high-energy particle population.

Magnetospheric Disturbances. Substorms involve the rapid release of accumulated magnetic energy in the form of energetic particles and electric currents. Due to their transient character and spatial extension, single spacecraft point measurements of plasma properties within the magnetosphere during a substorm are not sufficient to resolve the basic processes taking place. The GEO station, together with remote probes (small measurement platforms launched as free-flyers or tethered vehicles from the servicing shuttle or space station), can overcome this difficulty, providing new vantage points to selectively study the space-time character of substorms. Observations of plasmapause motion, the structure of the auroral oval visible to the GEO station (presuming a North American parking orbit), and the variations in electric and magnetic fields and particle fluxes at remote probe sites will be difficult to make prior to the GEO station and most probably will be required to resolve the substorm question.

General magnetospheric storms will also be of great interest since there will be numerous opportunities to make observations of many different transient phenomena. The detection of high-energy particles precipitating into the middle-latitude atmosphere could be readily done using a scanning

X-ray detector and imagers working at longer wavelengths. To resolve questions concerning radial variation of quantities, radially tethered remote probes offer an opportunity to separate effects acting over distances of hundreds of kilometers that are obtained through remote scanning. In addition, in situ measurements from remote probers should provide information about structural changes in the magnetosphere associated with substorms.

General magnetospheric storms will provide important targets of opportunity for space station study. The evolution of the ring current, for example, will be an important aspect of magnetospheric storms which can be intensively studied from GEO and a suitable arrangement of remote probes. The LEO station, in contrast, will provide a suitable platform for studies of middle- and low-latitude particle precipitation during magnetic storms.

Relativistic electron precipitation (REP) events have been recently recognized as a feature of the midday auroral zone. Localized in latitude and local time, REP events appear to provide an important loss mechanism for trapped electrons of high energy. The processes responsible for REP's are thought to involve the generation of plasma waves deep in the magnetosphere. However, few details are available, and an extensive LEO and GEO observational program could provide the facts needed to understand the REP phenomenon.

ATMOSPHERIC PHYSICS

Background

The advent of the Shuttle/Spacelab/Space Station era in the 1980's will provide unique opportunities for comprehensive studies of the atmosphere. Some progress has been made in understanding the Sun-Earth environmental system during the last decade, but major advances are needed before a working understanding of the basic behavior of our global weather system is obtained: the Sun-weather relationship, the role of anthropogenic constituents on the atmosphere, the coupling of the lower and upper atmosphere, to name a few examples.

The large weight-carrying capability of the early Shuttle/Spacelab missions will allow complex, large-aperture and long-focal-length remote sensing instruments to be carried aloft and to begin make-up global measurements of the type which cannot be carried out with the smaller free-flying satellites in use now. Cryogenic cooling systems can also be incorporated in the infrared instruments to give vastly improved signal-to-noise ratios. During the last couple of years, a large body of literature has been generated on the diverse and important scientific problems that such a Spacelab-borne instrument complement can address in the early to mid-1980's. The major limitation of Spacelab-based observations appears to be related to the limited flight duration. The availability of similar instrument complements on long-duration Space Station missions will result, for certain classes of problems, in significant enhancement in the scientific return over what is anticipated for Spacelab. Also, heavier and more elaborate payloads will be possible; larger telescopes, a more extensive complement of independent pointing controls, larger and more directive radio antennas, better cryogenics, and higher-power laser radar (lidar) transmitters are some of the possibilities presented.

Over the past several years, careful studies have been made of an optimum combination of atmospheric instrumentation for the Spacelab payload known as AMPS (Atmosphere, Magnetosphere and Plasmas in Space). Table 1 shows the proposed complement of instruments and the experiments for which they can be used in short-duration, low-Earth orbit.

Some of these instruments are described in more detail in the following subsections; however, a single example, that of the lidar, will illustrate the remote sensing concept. A downward-pointing tuneable dye laser can transmit pulses that are scattered resonantly from minor constituents such as neutral sodium (80-100 km) and ionized magnesium (100-150 km), giving both their global distribution and (by the use of high-resolution interferometry) the motion field of the lower thermosphere. Differential absorption of Rayleigh scattered UV pulses from the neutral atmosphere below 30 km, on the other hand, permits measurement of ozone and other absorbing constituents. This is just one of the instrument techniques planned for early Spacelab development that will be greatly enhanced by long-duration flight as a permanent space station.

TABLE 1. PROPOSED AMPS EXPERIMENTS

EXP. NO.	EXPERIMENTS	LIDAR	CRYOGENIC LIMB SCAN	FABRY-PEROT INTERFEROMETER	MICROWAVE LIMB SCAN	UV/VIS.	SUBSATELLITE CLUSTER IN SITU	IR INTERFER., FAR	IR INTERFER., NEAR	SOLAR/STELLAR OCCULTATION	
1	MINOR CONSTITUENTS	X	X		X			X	X		LOW TO MEDIUM LATITUDES
2	CHEMICAL/DIFFUSION EQUIL.					X	X	X		X	
3	METEORIC MATERIAL	X	X		X	X			X	X	
4	D-REGION CHANGES	X	X	X	X	X		X			
10	TEMPERATURE (80-120 km)	X	X	X	X						
11	EDDY DIFFUSION	X	X	X	X			X		X	
12	COMP/WIND IN THERMOSPHERE			X		X	X			X	
14	ATMOSPHERIC TIDES	X	X	X		X			X	X	
15	IONOSPHERIC CURRENT SYSTEMS			X			X				
18	ATOM/MOLECULE PHYSICS	X		X		X			X		
8	ANOMALOUS/AURORA	X	X	X	X	X	X	X			POLAR
9	PARTICLES VS. O_3	X	X		X			X			
13	PART./JOULE HEAT			X			X				
16	PHYSIC. PROC./AURORA			X		X	X				
17	SOLAR/MAG./CLIMATE	X	X	X	X	X	X	X	X		
5	VIB. EXCITED OH	X	X		X				X		NEED DEVELOPMENT
6	OI VAR. (80-120 km)		X		X	X	X				
	NO. OF EXPERIMENTS	11	11	11	10	10	8	7	6	5	

Advantages of an STO

A polar orbit would be greatly preferred for the LEO station, but much useful information could be obtained from one of high inclination ($\sim 55°$). The completely new approach of a GEO station will open the door further for observations of the type which have been hitherto impossible, mainly in the area of hemispheric imaging. This global view of light scattered or emitted by minor atmospheric species will enable the dynamics of the entire global atmosphere system to be studied continuously, without orbital interruptions. The atmosphere can be monitored on its time scale and not that of the spacecraft. Sudden changes produced by events such as volcanic eruptions or stratospheric warmings may be reacted to quickly, as well as sudden outside events such as flares and substorms. Changes associated with the 27-day solar rotation may be readily observed in all meteorological parameters.

Observations of the Earth's limb from GEO will be possible at microwave frequencies, giving height profiles at all latitudes on the day and night sides. Scattered light from the Earth's disk will make ultraviolet and visible observations difficult on the limb due to the reduced angular distance between the Earth's surface and the limb region of interest. Development of a "tellurograph" (named by analogy with the solar coronagraph) would certainly make ultraviolet measurements possible, though the visible region is less certain.

The large variety of imagery possible from GEO argues very forcibly for the essential role to be played by a trained scientist in the Space Station, backed up, of course, by an extensive scientific team on the ground. Advantages in pointing and adjustment of instruments as well as the ability to make real-time decisions on how to respond to targets of opportunity were demonstrated in the solar program of Skylab to be real advantages of man's involvement. Further, it seems likely that a highly trained specialist would, in the course of a 3-month mission, gain competence and scientific insight through continued handling of new scientific data even more than a specialist located on the ground.

Moreover, a Solar-Terrestrial Observatory of the type envisioned here for the Space Station would lead to important and productive cross fertilization of the disciplines.

Program of Investigations

The atmospheric observations envisioned for the Space Station are all based on remote sensing using different portions of the electromagnetic spectrum; therefore, this section is organized along standard spectral divisions. Each subsection contains representative scientific problems and instrumentation to be used.

Ultraviolet Observations from the GEO Station.

a. Ozone. Global maps of ozone may be obtained using a telescope, an adjustable ultraviolet filter, and a digital camera for observing ultraviolet light scattered in the Earth's atmosphere. Ozone absorbs ultraviolet radiation between 2000 and 3000 Å. The absorption cross section is largest near 2550 Å and becomes smaller at longer and shorter wavelengths. An adjustable ultraviolet filter which would isolate portions of the spectrum between 2550 and 3000 Å would permit the measurement of ozone at different altitudes in the atmospheres. Using on-board data processing, a real-time display would show the global ozone distribution corrected for geometric factors. Using this display, the scientist-astronaut would compare variations in the global ozone with real-time displays of other atmospheric parameters such as the global temperature distribution at a particular pressure level or the global precipitation of charged particles into the atmosphere. He could then adjust the ultraviolet filter in order to display the ozone distribution at other altitude levels, thereby interactively following the evolution of ozone changes and the physical processes which cause these changes.

b. Charged particle precipitation. Charged particle precipitation in the Earth's atmosphere produces ultraviolet radiation. These same charged particles also produce odd-nitrogen (nitric oxide and atomic nitrogen) by bombarding molecular nitrogen and molecular oxygen. Global pictures of the ultraviolet auroral emissions are indicators of the global production of odd-nitrogen. Increases in the amount of odd-nitrogen in the mesosphere and stratosphere lead to decreases in the amount of ozone. The principal ultraviolet emissions from charged particle bombardment of the Earth's atmosphere are: the atomic oxygen line at 1304 Å, the atomic nitrogen lines at 1495 and 1745 Å, the molecular nitrogen Lyman-Birge-Hopfield bands between 1300 and 2000 Å, and the molecular nitrogen Birge-Hopfield bands shortward of 1100 Å. The spectral region between 1400 and 1700 Å is particularly well suited for measuring emission from charged particle bombardment since the atomic and molecular nitrogen emissions are optically thin. In this wavelength range, aurora may be observed on the daylight as well as the nightside of the Earth. Charged particle impact may be measured from geosynchronous orbit using a telescope, a broad-band UV filter, and a digital camera. A real-time display will enable the scientist-astronaut to correlate the occurrence of auroral precipitation with other atmospheric phenomena such as upper-atmosphere motions and ozone distribution.

Atmospheric Experiment Using the LEO station.

Photochemical reaction chamber. The concentration of ozone in the Earth's stratosphere and ionosphere is determined by a large number of photodissociation processes and chemical reactions involving highly reactive constituents such as atoms and excited species. In a recent National Academy of Sciences study some 93 processes were considered. In principle, each individual process may be measured in a laboratory experiment and the effect of all 93 processes may be taken into account using a model atmosphere calculation. In practice, many of the reaction rates remain uncertain because of the difficulty of handling reactive species in the confines of a laboratory apparatus. In addition, certain of the photodissociation rates remain uncertain because of screening by other atmospheric constituents. Again, the limitations of confined laboratory space prevent the duplication of upper-atmosphere densities and path lengths. Also, the details of the high-resolution solar spectrum are not available, in every case, for use in the laboratory.

A photochemical reaction chamber in low Earth orbit may be the solution to these difficulties. The unattenuated solar spectrum is available. A large reaction chamber may be fabricated from the expended external tanks of the shuttle. For studies duplicating reactions and photodissociation processes in the mesosphere and stratosphere, a window of fused silica will permit solar radiation longward of 1600 Å to enter the chamber. For studies duplicating photoionization processes in the thermosphere, a windowless entrance for the solar radiation and a flowing gas system will enable ionization reactions to be produced.

The photochemical reaction chamber should be instrumented with diagnostic equipment to determine the densities of the reacting species. The chamber may be used to measure individual reactions; or, since it will nearly duplicate the actual atmospheric environment, it may be used to test the interaction of a large number of constituents. This last feature would permit the testing of the effect of impurities on the Earth's stratosphere before the actual introduction of the impurity into the Earth's atmosphere.

<u>Studies of the Visible Spectral Emissions from the Atmosphere</u>. High-resolution spectroscopy in the visible region of the spectrum offers a number of rewarding experiments of the monitoring type as well as many possibilities for future developments. The major immediate goals for a long-lived space station mission would be the direct mapping of tropospheric and stratospheric winds inferred from Doppler shifts of absorption features in the spectrum of scattered

sunlight. Wind speeds of a few meters per second can be obtained in this way, both at cloud tops and on the horizon. It should be noted that the cloud-top wind is the actual motion of cloud particles, not the apparent motion obtained by pattern motion studies.

In addition to these low-altitude parameters, one can monitor the mesopause wind and temperature from the OI (5577 Å) nightglow; the thermospheric winds and temperatures are easily obtained in the day and with somewhat reduced spatial resolution at night using OI (6300 and 5577 Å) line shapes and positions. During the day and over the auroral oval one can use the OII (7320 Å) ion line to determine large-scale ion temperature and drift speeds in the F-region, again from line shape and shift. This list is meant to be representative, not exhaustive.

The major instrumental requirement set by these spectral studies is high resolution, throughput, and stability. The use of a versatile Fabry-Perot interferometer with multiple etalons is clear. However, it may be possible to improve this complex by adding a single wide-angle Michaelson interferometer as the highest resolution element. This instrumentation will also form the basis of the high-resolution lidar studies. Here the major change would be the use of a controlled rather than natural source of excitation and scattering. This technique was discussed earlier in the introductory portion of this section.

It should be noted that there are significant differences in the studies that can be carried out from LEO and GEO. From GEO, horizon scanning in the troposphere and stratosphere will be difficult. However, the lack of relative motion will simplify the disk measurements and make possible the creation of a hemispheric "Dopplergram" showing atmospheric motions. The ability to watch the development of a particular dynamical event is clearly improved by observing from GEO. The lower-altitude polar orbit has a very significant advantage when altitude profiles are of primary importance.

Infrared Instrumentation. The role of infrared instrumentation on a space station is largely a continuation of an evolutionary process begun in the small, automated satellites. Vertical temperature profiles in the lower atmosphere, sea-surface temperatures, and cloud cover will continue to be important in terms of depicting the occurrence of various climatic situations.

To provide a real-time diagnostic temperature field for use in conjunction with man-directed experiments, some sort of basic vertical sounding capability should be included. A variety of instrument configurations would qualify for this application depending upon the vertical, horizontal, and time resolutions desired. In the case of pressure-modulated radiometers, this capability could be available for altitudes up to 90 km. GEO would allow hemispheric temperature fields to be obtained at selected pressure levels (vertically averaged) up to approximately 90 km. Thus, much could be learned about the role of waves with short time and space scales in the energetics of the upper stratosphere and mesosphere and the interaction of such modes with the geostrophic wind. Information about various components of the wind fields at low pressures should be available from the Doppler shift of lines.

The study of atmospheric composition should profit greatly from space station platforms. In the mid-1980's several techniques now under development should be available to improve the spectral resolution and sensitivity of infrared instruments. These include cryogenically cooled interferometers for use both in emission observations and solar-stellar occultations, laser-diode, and laser-heterodyne instruments. The long-duration missions implied in the space station concept will allow the necessary statistics to be gathered regarding the background concentrations of trace species and the magnitude of natural fluctuations both of short- and long-term nature. An important aspect of a manned involvement is maintaining the integrity of instrument performance and absolute calibration necessary to detect secular trends in the composition of the atmosphere due to pollutants.

Another new technique which may be available for monitoring the dispersion of man-made pollutants in the troposphere and their mixing into the stratosphere is correlation spectroscopy.

With sufficiently large telescopes, infrared limb sounding from GEO should be possible. This would allow nearly total latitude coverage at two local times on a nearly continuous basis but probably with a significantly lower vertical resolution than can be achieved in low Earth orbit.

Microwave Measurements. A manned space station, both LEO and GEO, will provide a unique platform for performing microwave (as used here, the term "microwave" also includes millimeter and submillimeter wavelengths) measurements of the Earth and its atmosphere which are relevant to improving our knowledge of solar-terrestrial relations and basic atmospheric processes. Short-term measurements which probably will have been performed previously from Shuttle sortie missions can be used to demonstrate the technique and answer certain questions, but important questions involving seasonal or longer variations and monitoring applications require a space station type platform. A GEO station can provide the first platform from which high-resolution microwave images and limb sounding can be performed; a manned space station is an appropriate platform for such measurements since a large ($\sim$25 m diameter) antenna is required and a trained operator could make real-time decisions concerning the mode of observation.

Microwave techniques can be used to measure profiles of atmospheric temperature, pressure, certain molecular species, winds, and the magnetic field over certain altitude ranges between the surface and lower thermosphere and with varying degrees of accuracy. They can also be used to map precipitation, sea-surface temperature, soil moisture, and possibly other parameters.

Prior to the availability of the Shuttle, it was not feasible to use limb sounding techniques in the microwave spectral region because of the large antenna required. With the advent of the Shuttle, however, such techniques are feasible. Table 2 summarizes theoretical results obtained to date on measurements which can be performed by such techniques with present technology. However, microwave radiometer technology is advancing rapidly and producing

TABLE 2. THEORETICAL RESULTS OBTAINED TO DATE ON ATMOSPHERIC PARAMETERS WHICH CAN BE MEASURED BY MICROWAVE OBSERVATIONS OF THERMAL EMISSION FROM THE ATMOSPHERIC LIMB

Parameter	Altitude Range (km)	Accuracy
Kinetic temperature	0 - 100	1 - 3 C
Pressure	35 - 70	1%
Winds	$\leq$ 70 - 100	3 m/s
Magnetic field intensity	60 - 100	1%
O_2	90 - 120	*
O_3	15 - 90	*
H_2O	15 - 90	*
H_2O_2	25 - 50	*
ClO	30 - 45	*
CO	15 - 110	*
N_2O	15 - 50	*

*Meaningful accuracy is obtained over the indicated altitude range, given our present understanding of the atmosphere.

instruments with better sensitivity that are capable of operating at submillimeter and shorter wavelengths. The technology is anticipated to be sufficiently advanced by the time a space station is available that a much wider range of species than shown in Table 2 can be measured, including atomic O, OH, HO_2, NO, NO_2, HCl, and others.

The microwave measurements will be useful for improving our knowledge of atmospheric chemistry, energetics, and transport and will complement measurements which can be made in other spectral bands. An example of one problem of solar-terrestrial relations which microwaves can help solve concerns the energetics of the mesopause and lower thermosphere. The lower thermosphere is principally heated by the absorption of solar ultraviolet radiation by molecular oxygen. However, the temperature of this region is at its coldest near the summer pole, where there is continuous input of solar energy, and at its warmest near the winter pole, where there is no input of solar energy. Very substantial energy transport mechanisms must be operating to maintain such a temperature distribution. Knowledge of the spatial and temporal variations of relevant parameters in this region is far too scanty for quantitative modeling. The microwave measurements of kinetic temperature, O_2 variation, and winds in this region over a long time period should provide important inputs for understanding these mechanisms and how they respond to variations in solar parameters. Important complementary measurements in other spectral regions are also needed. For example, 15 μm emission to space by CO_2 is the major energy sink at the mesopause and should be monitored, as should the solar UV input. A space station could provide the first opportunity to perform such a wide range of interrelated measurements over a sufficiently long time period to determine patterns in the behavior of the parameters.

For LEO, an antenna of approximately 2 m diameter is required for microwave limb sounding. Such an antenna will provide vertical resolution of 3 km at the limb. It can also provide an order of magnitude improvement in resolution over that now planned in Nimbus experiments for images of sea-surface temperature and precipitation, both of which may be very important in studying solar-terrestrial relations.

For a GEO station, an antenna of approximately 25 m or greater diameter also capable of operating at millimeter wavelengths should be considered. With such an antenna, microwave limb sounding from geosynchronous altitudes is feasible. The antenna beam could be moved slowly around the limb as it is scanned in the vertical plane, giving latitude and altitude profiles of atmospheric parameters as a function of local solar time. The same antenna could be used in a conventional sounding mode to provide images or precipitation, water vapor, sea-surface temperatures, and atmospheric temperature profiles with horizontal resolution of $\sim$25 to 100 km as needed by global circulation models. The antenna could also be used in an active mode for measuring atmospheric species of very low abundance. In this mode the antenna would either transmit, or receive from a ground station, radiation which is swept in frequency through a resonance of

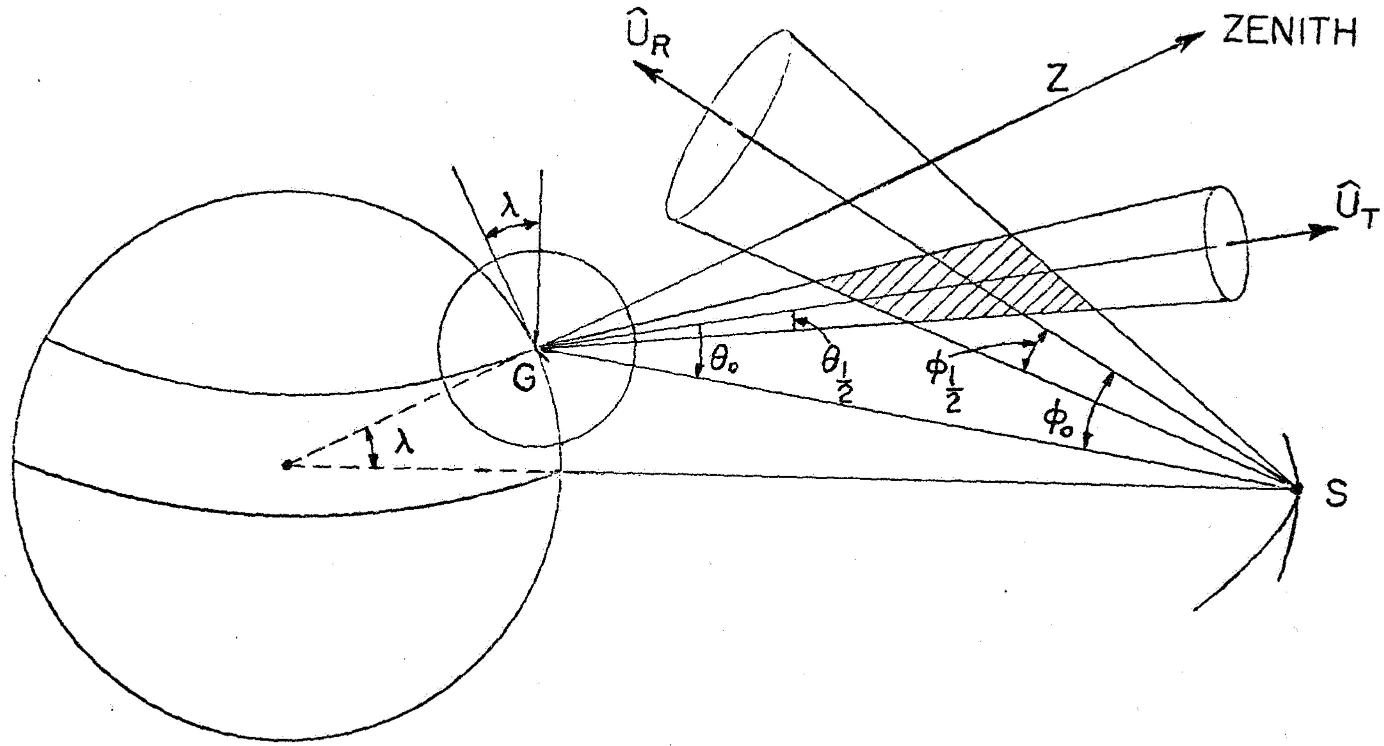

Figure 1. Spatial geometry of FISP system.

relative locations of the ground station G and space station S in the meridional plane. The transmitter beam of beam width $\theta_{\frac{1}{2}}$ points along $\hat{U}_T$, away from zenith Z, at an angle θ_o to axis GS. The transmitter beam of beam width $\phi_{\frac{1}{2}}$ points along $\hat{U}_R$ at an angle ϕ_o to GS. The scattering volume is shown by the shaded region. At small scattering angles ($\sim 3^\circ$ or less), the plasma wavelength probed by the radio signal is greatly increased, and the scattered spectral width is narrowed, with a consequent enhancement in signal-to-noise ratio. The Debye-length limitation also disappears. Contamination due to the direct signal from the transmitter is minimized by pointing the boresight of the monopulse reviewing antenna at the transmitter.

Calculations show that a transmitting antenna and transmitter such as that at Arecibo, together with a receiving antenna on the GEO station, will comprise a FISP system with adequate sensitivity to probe the electron distribution and plasma wave spectrum within the plasmasphere. If plasma waves are present outside the plasmapause where nonthermal excitation gives them an intensity comparable to those in the plasmasphere, the FISP technique will be able to study them also.

SUN-WEATHER RELATIONSHIPS

Background

"Sun-weather" studies are defined as investigations of possible processes in the lower atmosphere of the Earth that are initiated or controlled by changes in the output of the Sun. These changes can include solar variation in radiation (as in the solar constant, or in specific wavelength regions), in particles (as in physical properties of the solar wind, or in solar cosmic rays, or solar-modulated galactic cosmic rays), and in the extended magnetic field of the Sun (as in circumstances of the passage of interplanetary sector boundaries). Changes of short term (in the "weather") as well as long term (in regional or global "climate") are considered, although mechanisms involved in the two time scales may be quite different.

It is clear that studies of Sun-weather relationships are not an independent discipline. As a practical, interdisciplinary area, Sun-weather study relies on solar physics, magnetospheric physics, and atmospheric physics. Thus, programs in Sun-weather relationships envisioned here for the STO lean heavily on more fundamental programs in these other three areas. Instruments to carry out specific Sun-weather investigations will be a part of the working arsenal of equipment dedicated to solar physics, atmospheric physics, and magnetospheric physics. Indeed, while specific Sun-weather investigations should be an essential part of programs planned for the STO, major advances in our understanding of the Sun's influence on weather can also be expected from the broad advances anticipated from STO in each of the three more basic areas.

In anticipating possible programs for the STO in the Sun-weather area, it is recognized that there is less than complete understanding of the range of possible processes and mechanisms that could be involved. Some seem now to be obvious contenders that must be included, such as changes in the bulk radiation of the Sun or in specific spectral components that have known effects on the chemistry of the upper atmosphere. But there are many others, such as induced changes in the Earth's electric potential or a host of possible cloud formation mechanisms, that may be more important. The field of Sun-weather study is not sufficiently advanced, in 1977, to predict which theories or mechanisms will be the most likely contenders for study a decade from now. Thus, the approach is taken here of outlining broad areas rather than specific ones and of utilizing a varied and comprehensive list of equipment that might be needed in studying Sun-weather connections in 1985, hoping in this way to cover the widest range of possible important mechanisms.

This topic is approached recognizing that a number of recent developments show that a solar effect on weather is statistically established; the problem now is to determine the magnitude or importance of its impact on weather and climate and to understand its mechanism. In this regard the proposed schedule of a Space Station seems timely. It comes at a time when the world asks for tests and hard facts in the area of Sun-weather relationships, and the STO seems, for the reasons stated in preceding sections, almost uniquely qualified to provide these tests and facts.

Advantages of an STO

The proposed STO offers substantial advantages that may provide new and needed information in the study of solar influence on weather. These are:

(1) the capability to monitor the various outputs of the Sun in a laboratory environment, with the possibility of in-orbit cross-calibration, instrument replacement, and the use of on-board, controlled secondary standards;

(2) the capability of real-time observations of specific solar effects on the terrestrial atmosphere, requiring simultaneous or time-correlated observations of both Sun and Earth;

(3) the possibility of testing specific hypotheses of Sun-weather connections, through the availability of high-capability atmospheric, magnetospheric and solar observing equipment, and the ability to concentrate on specific geographic areas of interest.

Of all the aspects of an STO, the solar-weather objectives are most interdisciplinary and demand the greatest real-time, innovative reaction by the staff of the Observatory. The very nature of these objectives asks for recognition of relationships between members of a complex sequence of events stretching from the Sun to the surface of the Earth. The ensemble of instruments and data displays on the STO will allow the Observatory scientists to focus on specific relationships and to follow them as they unfold and evolve. Complete automation to follow these varied relationships seems virtually impossible. Further, the real-time pattern recognition and correlative capabilities of the human mind may catch significant relations that could easily elude notice during subsequent processing of recorded data at a ground site.

Near-real-time and extended analyses of data by a team of specialists on the ground are also essential. The former will provide information for baseline observation plans that can be transmitted to the STO. However, such baseline plans will be most effectively carried out and reinforced through the innovations of the on-board STO scientific staff.

Program of Investigations

Table 3 lists a program of potential investigations that follow from our current understanding of solar-weather connections. The left-hand column contains a brief statement of investigations with a statement of purpose. The middle column gives the advantages to be gained by conducting this investigation from a manned space station. In some instances the investigation will draw support from relevant unmanned spacecraft. The last column recommends the appropriate orbit for the STO.

The investigations are necessarily general, since at this stage a comprehensive attack is what seems to be most needed. Some suggestions are more specific than others, but pinpointing specific mechanisms for trial is avoided. Moreover, the possible mechanisms and solar-weather

TABLE 3. POTENTIAL INVESTIGATIONS OF SUN-WEATHER RELATIONSHIPS

Investigation	Advantage of Space Station	Orbit
1. Measure the solar constant $S = \int_0^\infty S_\lambda d_\lambda$ on a continuous basis. Accuracy ~ 0.1 percent. Purpose: To establish whether and by how much the total solar output varies over time scales of days to months.	Allows maintenance of calibration under "laboratory conditions" with ability to check, replace.	Any.
2. Measure the ultraviolet and soft X-ray spectral irradiance of the full solar disk, with correlated measurements of terrestrial atmospheric composition and ionization. Purpose: To diagnose solar-induced change in atmospheric composition at times of solar activity.	Capability of simultaneous "up" and "down" looks, and advantage of being on station as solar activity occurs and develops.	LEO (middle to high inclination) for first investigation. GEO for more extensive coverage.
3. Collect visible-light images of the entire globe and of specific selected areas at times of solar changes. Coverage of terrestrial areas should include cirrus coverage, cloud patterns, ice cover, albedo, Doppler wind velocities, temperatures. Examples of areas of specific interest are the Gulf of Alaska or specific regions of the tropics. Purpose: To allow a broad attack on questions of weather change related to solar change, with capability of examining specific hypotheses and specific events.	Flexibility, comprehensive coverage. Ability to check on suspected mechanisms in specific areas. Ability to observe real-time events.	LEO. Prefer high-inclination orbit for pilot study. GEO with two free-flyers for total Earth coverage.
4. Monitor atmospheric temperature distribution and wind velocities as function of height over globe, with capability to concentrate on geographic regions of interest. Purpose: To improve the definition of day-to-day weather change and weather systems.	Flexibility; ability to examine specific regions.	LEO (middle to high inclination) for pilot study; then GEO.
5. Measure high-latitude atmospheric responses to cosmic ray flux modulation, particle precipitation, and aurorae by monitoring these fluxes and events with concurrent measurement of cloud cover, atmospheric composition, temperature, and velocities. Purpose: Examine possible direct responses in specific selected regions such as the auroral oval.	Flexibility; ability to concentrate on specific areas to test specific theories; on-board availability of many diagnostic tools.	LEO (high inclination) for preliminary study; then GEO.

TABLE 3 (Concluded)

	Investigation	Advantage of Space Station	Orbit
6.	Monitor lightning frequency and intensity and their spatial and temporal distribution over the Earth. <u>Purpose</u>: To examine temporal and spatial variation in the Earth's electric field generator as a possible link between solar variability and weather.	Permit flexibility and an intelligent search. Capability of studying targets of opportunity such as extensive thunderstorms.	LEO (equatorial orbit) for preliminary study. GEO for more extensive coverage.
7.	Monitor the dust veil of the atmosphere (globally), with capability to follow specific disturbances such as volcanic eruptions. <u>Purpose</u>: To complete overall diagnosis of weather change and climate change.	Flexibility to zoom in and to follow targets of opportunity. Availability of a large platform for complex equipment.	LEO.
	<u>Related Experiments</u>		
8.	Continuous monitoring of solar wind velocity, density, magnetic field to identify effects of coronal holes, high-speed streams, crossing of magnetic sector boundaries on the Earth's magnetosphere and atmosphere (must be done from other spacecraft or free-flyers outside the magnetosphere).		
9.	Thermal mapping of ocean temperature and currents (longer time scale changes).		
10.	In-orbit measurement of brightness of outer planets throughout spectrum should the current anomaly of planetary brightness variations persist; orbital measurement should allow accuracy improvement.		

effects considered are recognized as being incomplete.

Almost all of the experiments proposed here involve apparatus which will serve other areas of research on board the Space Station: solar physics, magnetospheric physics, and atmospheric physics. The specific equipment is listed in the preceding sections.

The observational capabilities given in Table 3 provide a typical set of tools to investigate the class of scenarios suggested currently for the solar influence on weather. For example, the option that any appreciable variation of solar radiation could have a fairly direct influence on the Earth's atmosphere is addressed by items 1 through 4. Similarly, the thought that solar modulation of ionizing particles reaching the atmosphere may influence cloud mechanics, and hence weather, can be investigated by a combination of items 3, 4, and 5. Likewise, the idea that solar-induced changes of electrical conditions in the ionosphere interact with meteorology is addressed in items 3, 5, and 6. The concept that solar particle radiation filtered by the Earth's magnetosphere may change ozone concentrations in northwestern North America, resulting in the formation of cold anticyclones that propagate across the continent, can be investigated by items 2, 3, and 4. These are examples drawn from contemporary literature.

Even more important, however, is the encompassing ability of the instrumentation complement, when it is finally selected, to test refined and still-to-be-proposed scenarios that will surely come forward between now and the advent of the STO. In actual STO operations, a specific observation plan could be tailored to each of the prime candidate mechanisms for solar influence on weather and climate. At the present time, the observations to be made must be discussed in general terms as above. Ultimately the observing campaigns must be quite specific. This is the feature that distinguishes the STO from the traditional monitoring observations.

CONCLUSIONS

The Workshop resulted in a recognition that solar-terrestrial physics has become a discipline in its own right. There is a growing realization that the coupling of the system — Sun/solar wind/magnetosphere/atmosphere — is a real one and that an understanding of this coupling may have significant influence on a well-planned interaction of man with his environment.

That solar-terrestrial physics may be considered a single, unique discipline was demonstrated by a common interest among the participating scientists in both appropriate instrument techniques and the same research problems. Among the latter, the similarities in the solar physicist's concern with an understanding of the complex flare phenomenon and the magnetospheric physicist's interest in the physics of substorms were repeatedly cited. The Workshop concluded that an STO would be an appropriate vehicle by which the discipline of solar-terrestrial physics should be pursued from space.

The importance of a space station observatory was demonstrated by the necessity for long periods of essentially uninterrupted observations of both solar and terrestrial features. In the former case, for example, arguments were developed for an accurate monitoring of the solar constant as input for sophisticated weather analysis and climate research. The Workshop also defined a number of other monitoring programs well suited for an STO, necessary for a viable solar-terrestrial program, and ripe for consideration in the early 1980's. Among these programs the solar group identified as particularly valid for study are:

1. Regions of emerging magnetic flux on the Sun. These seem to have profound influence on the development of active regions and their flare productivity.

2. Coronal holes. These are closely linked with high-speed solar wind streams and, thereby, with magnetospheric responses.

The magnetospheric group drew attention to the following areas where investigation is sorely needed:

1. Electric fields and currents. Particular emphasis should be placed on the Joule heating of the atmosphere and the generation of electric fields directed parallel to the magnetic field lines.

2. Low-energy plasma dynamics. Both in the plasmasphere and plasma trough this cold plasma and its interaction with the hot plasma populations in the outer magnetosphere must be understood.

3. Wave-particle coupling processes. These can affect the stability of the radiation belts and can lead to the establishment of kilovolt electric potentials along auroral field lines.

4. Magnetospheric storms and substorms. The determination of the processes which trigger and then deposit large quantities of energy during these transient phenomena should be made.

Important programs identified by the atmospheric group are:

1. Ozone layer. This is crucial for the screening of solar UV radiation and has important medical implications.

2. Tropospheric and stratospheric winds. The routine mapping of these winds would be of great benefit to meteorologists.

3. Temperature of the sea and lower atmosphere. Such temperature profiles, from infrared and microwave monitoring, are essential in terms of depicting the occurrence of various climate situations.

The solar-weather group considered as particularly appropriate monitoring programs related to:

1. Variations in the Sun's radiation. These could have a fairly direct influence on the Earth's atmosphere.

2. Solar modulation of ionizing particles. This may influence cloud mechanics.

3. Cyclogeneses in the Gulf of Alaska. This may influence the weather pattern in North America.

4. Development of tropical storms. The devastating effects of such storms might be lessened by advanced forecast techniques.

The Workshop participants also expressed the view that more research-oriented programs whose immediate benefits are less obvious can be eminently well accommodated on a solar-terrestrial observatory.

The Logan discussion on coordinated solar-terrestrial studies generated several new ideas for future instrument techniques. These ideas grew out of the lively interaction between the different discipline groups and the realization that a permanent space platform would furnish greatly increased opportunities.

Perhaps the most noteworthy exchange of ideas occurred between the solar physicists and the atmospheric physicists. In considering observations of the Earth from GEO, the atmospheric physicists found themselves facing observational challenges that are very similar to those in observing the Sun. They developed the idea of imaging the entire hemisphere of the Earth simultaneously and using various wavelengths to determine hemispherical composition. Then by measuring the Doppler shift and broadening of specific spectral lines, the winds and temperature could be obtained. Thus, the terms "dopplergram" and "ozonogram" became parts of a new observational technique, "global atmospheric imaging," which could be applied over a large wavelength range from ultraviolet through microwave.

One of the more exciting creations was the "tellurograph" which was derived from its solar predecessor, the coronagraph. Here the use of an occulting disk when observing the Earth from geosynchronous altitude would permit limb scanning studies of the atmosphere around the entire globe in the ultraviolet and possibly visible wavelengths. This global limb scanning would permit the measurement of atmospheric constituents as a function of altitude as well as latitude around the globe and as a function of local time during the course of an orbit.

In solar physics the idea of solar situation monitors was developed. These monitors would follow solar activity in a variety of wavelengths and would serve as cueing devices from which more detailed observations of transient solar phenomena, such as solar flares, could be controlled. Through the use of these solar situation monitors, the on-board science staff will be able to maximize the scientific return by selecting and pointing specific instruments in the solar cluster for tailored observation of the particular phenomenon taking place.

Magnetospheric studies were seen to benefit greatly from remote sensing techniques. Most all of the instruments to be developed for low-altitude Spacelab flights would find greatly enhanced usage at GEO. For example, the electron acceleration and wave injection facilities discussed in the AMPS program will return extremely important results when applied in the "heart of the magnetosphere" at GEO.

New techniques such as forward incoherent scatter radar studies using a ground-based transmitter and a receiver at GEO and a predispersed radio pulse to maximize the interaction with the ambient plasma at a point distant from the orbiting transmitter were also presented as techniques to remotely probe the magnetospheric plasma populations. In addition, remote imaging of the plasmasphere from GEO using resonantly scattered He 304 emissions was discussed.

The preceding techniques represent examples of new observational approaches which become feasible with a permanently orbiting space platform. Techniques such as those used in coordination can give the simultaneous, large-scale observation of the solar-terrestrial system which will be necessary to delineate the controlling physical processes.

A main theme through the whole discussion was the man-in-the-loop notion, strongly endorsed by all four subgroups. It was argued that the inclusion of man in situ often may be of decisive importance, as in a coronal transient phenomenon or the sudden development of a tropical hurricane. Many other targets of opportunity were listed by the Workshop participants. Most research-type experiments will not be executed with the required performance to solve the problem in question without the intervention of a trained observer in the laboratory. Also, the painstaking calibration and accuracy in measurement often needed and the high pointing accuracy required indicate the necessity for manned intervention in well-planned observing sequences. With the sophisticated instrumentation being contemplated for a viable solar-terrestrial observatory, other needs are highly likely to occur. These needs may include repair activities or the flexibility for observing complex phenomena.

APPENDIX A

AGENDA

Monday, February 14, 1977

8:30 - 8:40	Introductory Remarks	Don Williams, NOAA
8:40 - 9:10	Keynote Address	Rick Chappell, MSFC
9:10 - 9:30	NASA View of Space Station	John Disher, OSF Bill Taylor, OSS NASA Headquarters
9:30 - 10:00	Space Station Characteristics	Bill Huber, MSFC
10:00 - 10:30	Manned Solar Observations from Skylab	Owen Garriott, JSC
10:30 - 11:00	Solar Facilities on Spacelab	Loren Acton, LMSC
11:00 - 11:30	Magnetospheric Facilities on Spacelab	Jim Burch, UTSA
11:30 - 12:00	Atmospheric Facilities on Spacelab	Andy Nagy, U. of Mich.
12:00 - 12:30	General Discussion and Division into Subgroups: Solar Magnetosphere Atmosphere Sun-Weather	Don Williams, NOAA
12:30 - 1:30	Lunch	
1:30 - 5:30	Subgroup Discussions on Space Station Experiments	

AGENDA (Concluded)

Tuesday, February 15, 1977

8:30 - 10:30	Group Discussion of Subgroup Ideas
	Writing Assignments
10:30 - 12:30	Individual Writing Activities
12:30 - 1:30	Lunch
1:30 - 3:30	Individual Writing Activities
3:30 - 6:00	Public Reading of Subgroup Ideas
Evening	Rewrite Assignments

Wednesday, February 16, 1977

8:30 - 12:30	Consolidation of Ideas — Group Discussion
Afternoon	Finalize Draft
	Discussion of Future Conference
	Departure

APPENDIX B

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APPENDIX C

Space Sciences Laboratory

THE SOLAR-TERRESTRIAL OBSERVATORY AS A MAJOR MODULE OF A SPACE STATION

An Advocacy Document

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I. INTRODUCTION: MAN AND HIS TOTAL ENVIRONMENT

As man continues to push the limits of the resources available to him on Earth, it becomes increasingly important that he understand the physical processes which control the Earth's total environmental system. It is through such an understanding that man can hope to anticipate environmental changes and thereby plan and manage more effectively the utilization of these finite resources. Beyond the satisfaction of basic physical needs, the advancement of civilization toward an ever-improving quality of life is likewise dependent upon man's interaction with his entire environment.

The Earth's environment embraces not only the immediate surroundings of which we are visually aware but also a much larger region of space consisting of the atmosphere and magnetosphere which extends outward a hundred thousand kilometers above the surface of the Earth. This larger system is controlled externally by electromagnetic and particle energy from the Sun and internally by the dynamic interchange of energy between the solid Earth, oceans, the atmosphere, and the magnetosphere. It is this exchange of energy that determines the structure of the Earth's environmental system and that ultimately controls, for example, our large-scale climate and local weather patterns. If we can understand the interactive processes within the Sun-Earth system, we can predict and accommodate the terrestrial effects of changes that take place in the Sun.

Because of the interactive nature of the components of the Earth environmental system, man has realized that his ecological concerns must assume a global perspective. We have all been struck by the delicacy of our environment on a local scale, as for example in the pollution of streams and the resultant damage to biological systems. We are now apprehensive that this same delicacy is present on a global scale where the infusion of relatively minor quantities of pollutants into the atmosphere may have drastic effects on the characteristics of the stratosphere which protects us from the Sun's ultraviolet radiation. Stratospheric effects are but one symptom of the larger problem of assessing the effects of man's effluents on his sensitive environmental system. If we are to survive, we must protect this system; and to protect it we must understand the processes that control it.

Hence, we have in the Sun-Earth system a chain of coupled regions that are controlled initially by a variable solar input and subsequently by the processes in which energy propagates through the magnetosphere and atmosphere. This is a chain of events that generates those constituents of the atmosphere shielding us from solar ultraviolet radiation, that determines the nature of the ionosphere upon which we rely for essential communications, and that leads to the development of atmospheric circulation, the dominant force in our weather patterns and climate. It is the workings of this interactive system that man must strive to understand.

When we are successful in achieving this understanding, we will be able to compile long-range environmental forecasts, which will, for example, predict the effects of man's pollutants on the environment and give advanced information on major weather patterns in given geographical areas for periods of months or perhaps even years. These forecasts will be supported on a continuing basis by an adaptive observation program tailored toward specific measurements of the crucial parameters which drive the environmental system. Forecasts of this type, in the context of a working understanding of the solar-terrestrial system, are needed by policy makers, environmentally affected organizations, and individual citizens alike. Reliable projections of environmental factors can be a great benefit to the nation and to mankind.

Man now has the ability to move into space with sophisticated instrumentation to observe his environment and to probe its intricate workings. A program to marshal this capability and ultimately to realize responsible environmental management is within our reach. It is, however, a program of substantial challenge and magnitude. In particular, it is a program that cries for the scope and versatility of a manned space station. The dramatically successful solar observatory on the Skylab space station is typical of the scale of instrumentation that must be brought to bear on this objective. Lesser capabilities will be inadequate. Further insight into requirements for this program will unfold in the course of subsequent paragraphs.

The recognition of this opportunity to benefit mankind is not new, of course. It was addressed deeply in the NASA Outlook for Space. NASA programs have studied the Sun-Earth system for a number of years, beginning with the early Explorer satellites which produced a wealth of information on the system's morphology and dynamics. With the Shuttle-Spacelab era will come opportunities to carry out experiments involving the scientist directly in probing specific physical mechanisms which control the Earth's surroundings. During the short-duration Spacelab flights, new instruments and experimental techniques will be developed for the remote sensing of the Sun, the atmosphere, and the magnetosphere and for controlled active probing of the atmosphere and magnetosphere. Many of the experiments developed for Spacelab will have direct extension to longer duration missions. An example of this is the global measurement of features of the Earth's atmosphere and its seasonal variation and solar cycle dependence.

These longer missions should be carried out in a manned Space Station having a Solar-Terrestrial Observatory that would be operated initially in a low Earth orbit with a follow-on mode at geosynchronous orbit. This observatory could be one module of a station carried to orbit in the Space Shuttle. Through continuous observations of the Sun and Earth, the observatory will measure the relationships between solar activity changes and terrestrial responses. It can make global assessments of the effects of natural and man-induced trace materials introduced into the atmosphere and magnetosphere. The simultaneous, long-duration remote sensing of the Sun, the magnetosphere, and the atmosphere should give us the insight and understanding that is necessary to model, predict, and accommodate changes in our complex environmental system. Environmental management is a crucial part of our future; the Solar-Terrestrial Observatory will play an essential role.

Fundamentally, we have but two choices: gamble with our future or work to obtain a complete understanding of our Sun-Earth environmental system.

II. SOLAR-TERRESTRIAL INTERACTIONS

A. The Role of the Sun

The Sun is the dominant source of life-sustaining energy to the Earth. We think of its output as constant, but it is not, and even small variations in solar properties can have far-reaching effects on the Earth. The two basic means by which the Sun controls the terrestrial environment are the solar electromagnetic radiation and the solar wind.

The amount of solar radiant energy of all wavelengths received per unit time at the surface of the Earth, the solar constant (1353 watts/m^2), has enormous implications for the terrestrial environment from the outer reaches of the magnetosphere down to the Earth's surface. Ultimately, it is solar radiation that is the basic energy source driving the circulations of the Earth's atmosphere and oceans. Solar radiation is responsible for the ionization of the Earth's upper atmosphere to form the ionosphere, which is important to our understanding of the magnetosphere and its interaction with the solar wind.

The solar wind, which is the continuous (but not steady) flow of the Sun's coronal plasma and magnetic field into interplanetary space, plays both an active and passive role in its interaction with the Earth's environment. In the active mode the solar wind itself causes the final result: the deformation of the Earth's magnetic field to form the magnetosphere, and the recurrent modification of the magnetospheric structure which results in geomagnetic storms. Historically, recurrent (with the 27-day solar rotation period) geomagnetic storms were assumed to originate in hypothetical "M" (or magnetic) regions on the Sun. Only recently have these M regions been identified as coronal holes, large regions of predominantly open unipolar magnetic fields from which high-speed solar-wind streams flow. Because coronal holes have lifetimes of many solar rotations, the plasma flows emanating from them can perturb the Earth's magnetosphere cyclically over a period of many months.

In its passive role, the solar wind acts as a medium through which the Sun influences the Earth in a manner not possible without a pre-existing solar wind. Examples of this are the propagation of hydromagnetic shock waves, the channeling of flare-generated relativistic protons along the curved paths of the interplanetary magnetic field, and the modulation of the galactic cosmic ray flux received at the Earth.

Essential Solar Investigations

1. The Solar Constant

With the potential of today's technology for measuring the solar constant to an accuracy of a few tenths of a percent, the time is right to undertake a long-term program of space-based observations to measure accurately the complete solar spectral irradiance over the 22-year solar cycle. Space, as opposed to ground-based, observations are essential to eliminate the effects of atmospheric absorption, particularly in the important ultraviolet wavelengths. Even more importantly, the observation program should determine temporal fluctuations in particular solar spectral bands. The possible existence of large time-scale variations remains plausible because of our lack of conclusive understanding of the thermonuclear processes in the solar interior, as seen, for example, in the disparity between the predicted and observed solar neutrino flux. In addition, direct observations have provided recent evidence for short time-scale fluctuations, particularly in the EUV where there may be variations as large as 50 percent below 1600 Å depending on the level of solar activity.

For ionospheric and atmospheric physics, the far-reaching implications of these variations in the solar constant underscore the necessity for sophisticated instrumentation on the Solar-Terrestrial Observatory which would measure the solar spectral irradiance over the complete spectrum for the integrated solar disk as well as for selected active regions. Selected instrumentation would also permit observation of spectral bands of particular interest, such as the 1200 to 3000 Å region which includes the Lyman alpha absorption important to the D region of the atmosphere. The spectral irradiance at X-ray wavelengths is also of interest, particularly its variation during solar flares and its correlation with increased ionization levels in the ionosphere.

2. The Solar Wind

A complete description of the solar wind necessitates measurements of particle densities, temperatures, flow velocities, and the vector magnetic field throughout the region from the solar corona to the Earth and beyond. Such a program would certainly involve in situ measurements of these quantities from satellites outside the magnetosphere. Yet, the "initial conditions" for the solar wind are provided by the Sun's corona, and thus our descriptive models of the solar wind will depend on how well we know these initial conditions. The corona is observed best from space where we can measure the coronal X-radiation and where the outer corona can be observed without waiting for a solar eclipse. A particular objective for space-based solar-wind observations would be the study of the formation and evolution of coronal holes and their relation to active region development and decay over the 22-year solar cycle. Since the coronal holes cause conditions in the solar wind which, in turn, cause geomagnetic storms, a study of their development characteristics could lead to the capability of predicting the geomagnetic storms for periods of months in advance. Soft X-ray telescope observations would yield the spatial extent and configuration of coronal holes as well as densities in surrounding regions while the hole is on the visible disk. For densities and magnetic field geometry within the hole region out to a few solar radii, coronagraph limb observations would be made. Magnetograph data would provide information on the three-dimensional magnetic field configuration in and around coronal holes as well as normalized intensity magnitudes.

3. Solar Flares

Both the solar constant and the solar wind are frequently subjected to extreme perturbations over a short time scale as a consequence of the eruption of solar flares in which 10^{25} joules of energy are released, with resulting extreme effects on the terrestrial environment. Solar flares of significant size produce increased X- and ultraviolet radiation, with subsequent increases in the D layer ionization that produce communications interference. During large flare events, such as in August 1972, current surges induced by the magnetospheric response to the flare have caused power disruptions across the northern United States and Canada. During a flare, plasma clouds are ejected by the Sun which impinge on the magnetosphere, producing large, impulsive geomagnetic storms. There are occasional flares which produce GeV energetic particles (solar cosmic ray flares) and MeV particles (called proton flares) which represent serious radiation hazards for manned spacecraft.

Because of the extreme effects of solar flares on the Earth's environment, a program for the prediction of the occurrence and magnitude of solar flares would be a vital part of a Solar-Terrestrial Observatory. Of particular interest in such a program would be the identification of flare precursors, the flare-triggering mechanism(s) and the acceleration mechanisms for electrons, protons, and heavier nuclei. A flare-alert system is a necessity for astronaut protection on the Space Station, particularly when it will be in geosynchronous orbit. Because of its relevance to the Space Station and to solar-terrestrial relations, this flare-alert system would be a natural component of the Solar-Terrestrial Observatory.

B. The Role of the Magnetosphere

As pointed out in the previous section, the solar wind exists continuously as a supersonic flow of magnetized plasma in which the magnetic field strength and flow velocity are significantly intensified in association with coronal holes. If one could turn off the solar wind, the geomagnetic field would revert essentially to that of a large subterranean bar magnet (or a dipole field). This pristine geomagnetic field would be filled with a plasma or ionized gas as an extension of the solar-ionized upper atmosphere, or ionosphere. Tidal dynamo effects would give rise to some circulatory motion of the geomagnetic plasma in addition to its general tendency to rotate with the Earth. However, no spectacular geophysical effects would be expected to result from this magnetized plasma under the conditions of dynamical equilibrium which would soon be established. The situation as it actually exists with the constant flow of the solar wind is quite different.

The magnetized plasma of the solar wind cannot penetrate closer to the Earth than approximately 10 R_E under normal circumstances because of deflection by the geomagnetic field. In the process of its diversion around the geomagnetic field the solar-wind plasma sets up a current system which tends to confine the geomagnetic field to a comet-shaped region or cavity known as the magnetosphere. The average power incident on this cavity due to the solar wind is $\sim 10^{13}$ watts. If this energy were completely excluded from the cavity, then variations in the strength of the solar wind would only change the size of the cavity; the cavity itself would extend only to about the lunar orbit, the circulation of the geomagnetic (or magnetospheric) plasma would still be dominated by the Earth's rotation and atmospheric tidal effects, and there would be no intermingling of solar-wind plasma and terrestrial plasma. Experiments conducted over the past few decades have established, on the contrary, that the magnetosphere has a long tail (several hundred R_E or more), that a strong circulation of plasma occurs—driven in some way by the solar wind, and that the solar wind is a major source of some of the magnetospheric plasma populations. The processes by which momentum, energy, and plasma carried by the solar wind gain access into the magnetosphere have not been identified. However, we do know that the solar wind magnetic field, which carries only approximately 1 percent of the total solar-wind energy, acts as a trigger, or modulator, which determines by its direction what fraction of the solar-wind power is coupled into the magnetosphere.

Gusts of the solar wind in which the embedded magnetic field is directed southward, or antiparallel to the Earth's magnetic field, result in the occurrence of magnetospheric substorms. During an individual substorm lasting approximately 1 hour, a total energy of $\sim 8 \times 10^{14}$ joules is dissipated in the high-latitude upper atmosphere. This dissipation, which is about equal to the total energy of a magnitude 6.7 earthquake, is absorbed almost totally at altitudes near and above 100 km. About half of the energy input is due to precipitation of magnetospheric particles, with the other half resulting from heating by ionospheric currents.

The key outstanding questions concerning substorms include the identification of the physical processes responsible for the triggering of substorm events; the acceleration and precipitation of magnetospheric particles; and the generation of large-scale current systems in the magnetosphere. We must, then, understand how solar-wind influences are transferred into the magnetosphere and how magnetospheric energy is dissipated in the upper atmosphere, and we must look further into possible mechanisms which may couple this energy downward into the stratosphere and troposphere.

The total energy dissipated in a large substorm is comparable to the total energy involved in certain large, low-pressure systems which are observed to develop in the Gulf of Alaska. Both phenomena have been statistically correlated with changes in the large-scale structure of the solar-wind magnetic field. It has also been pointed out that the angular momentum involved in the circulation of plasma at ionospheric heights is sufficient to account for these storm systems provided an efficient coupling mechanism (e. g. , viscous effects or planetary waves) is available. Such coupling phenomena are potentially of great significance in our study of solar-terrestrial effects, particularly since a large number of statistical correlations between solar activity and various meteorological phenomena have been identified.

Quite apart from the substorm process itself, another important energy source for the high-latitude upper atmosphere is the large flux of energetic solar protons produced by some solar flares. These protons have direct access to the polar caps within hours after the occurrence of a solar flare. Although the total power dissipated in the Earth's atmosphere during a flare is less than that associated with substorms ($\sim 10^9$ watts), the 1 to 100 MeV solar-flare protons penetrate into the stratosphere and down to the tropopause, where significant ionization is produced. This ionization could form nucleation centers for cloud formation or, as occurred in the August 1972 solar particle event, could result in a significant decrease in stratospheric ozone. In either case an altered thermal balance would be expected, and this could act as a trigger for other meteorological changes at lower altitudes.

Essential Magnetospheric Investigations

1. Charged Particle Energization and Transport within the Magnetosphere

Of the total energy dissipated in the upper atmosphere by the magnetosphere, roughly one-half is carried by energetic charged particles. Therefore, the mechanisms which accelerate the magnetospheric particles and cause them to be scattered into the atmosphere must be identified if this important aspect of solar-terrestrial interactions and its implications are to be understood. The available data from passive measurements are sparse enough to be consistent with a variety of proposed mechanisms. Now needed are active experiments conducted during varied geomagnetic conditions in which particle beams with known characteristics are injected into the magnetosphere and observed as they undergo the processes of acceleration and precipitation. The techniques and instrumentation required for definitive studies will be well developed on Spacelab missions and, hence, will be available for a manned Space Station application. In addition to particle accelerators, the required instrumentation will include visible and UV imagers for remote detection of the beams as they strike the atmosphere, and subsatellites equipped with particle and wave detectors for direct measurement of the beams. The proposed acceleration mechanisms include low-altitude processes and processes in the equatorial plane, near and beyond geosynchronous orbit. It is important, then, that these investigations be carried out in low-altitude orbit and at geosynchronous orbit.

In addition to mechanisms which act to accelerate particles, other mechanisms appear simply to change the direction of energetic particles, scattering them out of their trapped orbits and into the atmosphere. It is thought that interactions between particles and plasma waves are responsible for this scattering. These interactions are expected to be strongest near the equatorial plane and to depend critically on certain parameters such as the local ion density. Definitive experiments in this area can be carried out from the Solar-Terrestrial Observatory at geosynchronous orbit with the capability to release gases, such as lithium or barium, which alter the local ion density. By measuring simultaneously the particle and wave characteristics in the region of the release, a number of proposed mechanisms would be tested definitively for the first time.

While the processes of charged-particle energization and transport operate at all times in the magnetosphere, they are intensified significantly during substorms. A full understanding of the role of these processes in the Earth's environment requires that we identify the substorm triggering mechanism. At present we know that large substorms are triggered with a high probability when the solar-wind magnetic field has a southward component. In the magnetosphere, strong plasma flows have been observed in the nightside equatorial plane, causing attention to be focused on that region for the identification of possible unstable plasma processes as the substorm trigger. Simultaneously there occur widespread and dynamic displays of the aurora, produced by charged-particle bombardment of the atmosphere and resulting in significant atmospheric heating and increased ionospheric conductivity. These low-altitude effects have led to further suggestions that substorms are initiated there in regions of high conductivity. A low-altitude Solar-Terrestrial Observatory could provide definitive tests of such theories by controlled active stimulations of the ionosphere using particle accelerators and gas releases. An observatory at geosynchronous orbit would have the ability to obtain global images of the aurora, thereby identifying the time and location of the first signs of a substorm. Combining this information with simultaneous observations of the plasma flows and active probing in the equatorial plane would give a comprehensive picture of the substorm, the basic disturbance mechanism of the magnetosphere.

2. Transfer of Energy through the Magnetosphere into the Upper Atmosphere

The transfer of energy from the magnetosphere to the upper atmosphere by charged particles, electric fields, and currents occurs predominantly along magnetic field lines. Our understanding of these energy-transfer processes is limited by our lack of knowledge of field-line configuration and by our present inability to measure simultaneously the energy input to the magnetosphere, its flow along field lines, and the effects produced in the upper atmosphere. It is expected that these limitations could be overcome by a properly equipped Solar-Terrestrial Observatory.

The difficulty in determining magnetic field-line configuration lies in the dynamic effects which occur during substorms. During substorm times, a given magnetic field-line configuration can change from an equatorial crossing point of 6 R_E to a crossing at 10 to 20 R_E. Magnetic field lines can be traced both from low-altitude orbits where ion beams can be injected and optically tracked, and from geosynchronous orbit where particle beams can be fired down the field lines into the atmosphere where their interactions can be observed.

With the ability to map magnetic field lines under varying conditions, the Solar-Terrestrial Observatory could then be utilized to investigate the overall problem of magnetospheric-atmospheric energy transfer. Through remote-sensing measurements of solar and solar-wind phenomena conducted from the observatory itself, coupled with possible direct real-time probing of the solar wind by a companion satellite in the interplanetary medium, one could measure the particle and field energy incident on the magnetosphere as well as the solar electromagnetic energy incident upon the atmosphere. Then, by tracing field lines and measuring directly the fluxes of particles and the intensities of magnetospheric currents and electric fields from the orbiting observatory and its companion subsatellites, the flow of solar energy through the magnetosphere could be monitored. The atmospheric response to this magnetospheric energy input would be measured through the optical remote-sensing capability of the observatory.

This combination of techniques would give the broad picture of how plasma and wave energy is coupled from the Sun through the magnetosphere into the atmosphere where it contributes to atmospheric motions.

3. Magnetospheric Effects on the Stratosphere and Troposphere

The magnetic field lines from the Earth's polar cap continue into the region of the solar wind and so provide direct paths for energetic solar-flare protons to follow into the atmosphere. As mentioned previously, these 1 to 100 MeV protons penetrate the entire stratosphere where they may act to reduce the ozone levels significantly, hence upsetting the thermal balance of the atmosphere. From a Solar-Terrestrial Observatory in low Earth orbit one could measure directly the fluxes of energetic protons while monitoring simultaneously the concentrations of minor constituents, such as ozone, in the stratosphere. The remote measurement of stratospheric constituents could be accomplished using a comprehensive set of optical instruments covering the wavelength range from ultraviolet to infrared. These systems generally must have large apertures and optics, and in some cases must be cryogenically cooled. An effective program of this type will, therefore, require a large, versatile facility such as a manned Space Station whose long-duration missions will assure that the correct instruments will be in orbit when an event occurs.

In addition to the effects of solar-flare protons, changes in the large-scale structure of the solar-wind magnetic field (the sector structure) are accompanied by increased levels of magnetospheric activity and by intensifications of high-latitude atmospheric disturbances as measured by atmospheric vorticity indices. The energy dissipated in the upper atmosphere during substorms and the angular momentum carried by the circulating plasma in the ionosphere may, then, play key roles in the dynamics of the high-latitude troposphere.

The next step beyond the statistical correlations made to date would be to investigate possible mechanisms by which this energy and angular momentum are coupled downward through the stratosphere and into the troposphere. The role of a Solar-Terrestrial Observatory could be central to our eventual understanding of how magnetospheric energy may be coupled into the troposphere, affecting ultimately the weather and climate on a global scale. Needed are global measurements of cloud cover, coupled with altitude scans of atmospheric winds, vorticity, composition, and temperature from the 100-km level down to the troposphere. When combined with simultaneous observations of solar and magnetospheric energy inputs, these observations could provide definitive tests of mechanisms through which magnetospheric energy is coupled to low-altitude weather patterns.

C. The Role of the Atmosphere

Lying closest to the Earth and comprising a major part of what we visualize as our environment is the atmosphere. The atmosphere is a dynamic system consisting of several interactive layers: the troposphere where weather systems are found, the stratosphere where the Sun's ultraviolet radiation is absorbed, and, finally, the mesosphere and thermosphere where ionized atmospheric gas provides a basic link in worldwide communications. The characteristics of the atmospheric system are determined by a complex balance of energy inputs from the Sun, the magnetosphere, and the Earth as well as constant exchange of materials with the Earth's surface.

Despite an ever-increasing body of evidence correlating variations in the atmosphere (particularly weather and climate changes) with variations in the Sun, man has been unable to confirm specific physical processes which link the two directly, primarily because of the immense complexity and delicate characteristics of the atmospheric system. The correlations are nonetheless compelling, as, for example, the predictions based on solar cycle variations of droughts in the high plains areas of the United States in the mid-1970's. It appears that changes in the solar character trigger changes in the dynamics of the atmosphere both on a short-term basis, as in the case of individual geomagnetic storm effects lasting for days, and over the long-term sunspot cycle of 11 and 22 years. Even longer period changes have been observed, as in the case of the so-called Maunder Minimum, a period of some 70 years in the late 17th century. During this time, there existed a dramatic minimum in solar activity which has been correlated with the coldest excursion of the "Little Ice Age" in Europe and a concurrent drought period in the American Southwest.

Observations of tropospheric weather phenomena have been vastly improved with better descriptions of the global wave patterns (particularly over ocean areas) through the use of satellite pictures of cloud patterns. However, we currently have no better picture of what is to transpire in weather patterns than the 2-day forecast using predictability schemes developed in the 1940's and 50's. We must study the atmosphere globally in a unified manner, measuring chemistry and dynamics simultaneously. This approach combined with the observation of changing solar and magnetospheric energy inputs should begin to fill out our uncertainties and expose clues to the physical processes which are responsible for solar-related atmospheric changes.

The fragile nature of the atmosphere has been emphasized in the recent concern over the effects of minor constituents (a few parts per million) on the overall conditions in the stratosphere. A push to quantify the detrimental effects of freon has raised more questions than it has answered, primarily relating to the dynamics of the atmosphere and the degree to which other potentially harmful minor constituents are being added to and mixed within its different layers: the troposphere, stratosphere, mesosphere, and thermosphere.

Atmospheric dynamics consisting of winds as well as diffusion processes and the basic chemistry and energetics resulting from solar and magnetospheric influences are again the necessary parameters to be measured. These measurements would provide the knowledge necessary to model pollutant effects in advance, with the ultimate hope of carefully controlling our interaction with our atmosphere.

Essential Atmospheric Investigations

1. Global Atmospheric Chemistry and Dynamics

A fundamental element of the atmosphere which is common to all of the specific investigations is a knowledge of global atmospheric chemistry and dynamics. Techniques are being developed today for use on short-duration Spacelab flights of the early 1980's which will allow the measurement of atmospheric composition, temperature, and winds as a function of altitude throughout the different layers of the atmosphere. The early Spacelab flights will be ideal opportunities to develop the instrumental and experimental techniques and, as such, are a natural lead-in to long-duration Space Station operation. Atmospheric dynamics studies require the long observing times. We are concerned with not only diurnal effects, but with seasonal variations as well as longer term changes over periods of years (e.g., variations with the solar cycle).

Studies in atmospheric chemistry and dynamics would be conducted initially from low Earth orbit, preferably at an inclination high enough to give global coverage. These studies would utilize the comprehensive nature of the instrumentation on the Solar-Terrestrial Observatory, including the complete active and passive remote-sensing capability for the atmosphere in addition to simultaneously monitoring the solar electromagnetic output (the solar constant) and the input of energy from the magnetosphere through particle precipitation and joule heating. Passive plasma and wave measurements would be needed both from the observatory and from subsatellite packages which would transmit information back to the observatory.

The opportunity to place the Solar-Terrestrial Observatory in geosynchronous orbit opens a completely new capability. Whereas the low Earth orbit offers the unique capability to gather detailed height distributions of atmospheric parameters, global averages of the integrated system could be accomplished from geosynchronous orbit. From geosynchronous orbit the atmosphere could be viewed over an entire hemisphere, with the potential to scan compositions, temperatures, and wind characteristics over a large portion of the globe simultaneously. Experiments in this orbit would require new techniques which could be developed in Shuttle-Spacelab flights.

2. Atmospheric Response to Solar Changes

Although this topic is a part of the overall study of atmospheric dynamics which is mentioned above, its importance to Sun-weather studies and environmental change prediction is sufficiently compelling to justify separate discussion. This body of investigations would be directed toward understanding the response of the atmosphere, particularly the troposphere and stratosphere, to both short- and long-term changes in solar parameters combined with the concomitant magnetospheric changes. In particular, the atmospheric response to substorms (periods of hours), large geomagnetic storms (periods of days), solar rotation (27 days), and solar-cycle variations (periods of years) would be studied.

An approach to this investigation would include the continuous monitoring of solar electromagnetic outputs, coronal hole development, solar-wind variations, and magnetospheric substorm and storm conditions, with the careful remote sensing of atmospheric changes. In these investigations, one would try to separate and identify the effects of different inputs — the solar constant, the magnetospheric particle precipitation, the magnetospheric joule heating — in all levels of the atmosphere, with particular attention paid to the troposphere and stratosphere.

By measuring tropospheric response to these varying inputs, we should be able to postulate coupling mechanisms which could then be tested with a more specific set of experiments. We must invest in this type of activity if we are ever to reap the rewards associated with long- and short-range weather prediction.

3. Stratospheric Maintenance

As in the previous section, this topic is also a part of the overall atmospheric chemistry and dynamics problem which, because of its importance, must be addressed separately. The thrust of the investigation centers around understanding the processes that control and maintain the stratosphere, which is of basic importance as an ultraviolet shield. The stratosphere is affected by solar, magnetospheric, natural terrestrial, and man-made inputs. These inputs need to be separated and their effects quantified in order that adequate stratospheric maintenance can be assured through whatever protective measures are necessary.

The Sun can affect the stratosphere directly through the variation of solar electromagnetic radiation, particularly in the EUV wavelengths, and through the generation of high-energy protons which can penetrate the atmosphere down to stratospheric levels. These particle events (polar cap absorption) have been observed to modify ozone concentrations during large magnetic storms. The Sun, through the magnetospheric filter, can affect the stratosphere in other ways. For example, changes in coronal hole structures can change the solar-wind parameters which, in turn, can cause magnetic storms in which particle acceleration and precipitation into the atmosphere are intensified. This precipitation can modify the thermosphere drastically and produce NO, which if transported to stratospheric heights could have a significant effect on ozone content. The extent to which NO is produced and transported is currently not known.

Naturally occurring terrestrial events, particularly volcanic eruptions, can inject significant quantities of trace materials into the stratosphere. The injected material can persist for months and years. In addition to the natural inputs, man's manufacturing activities have reached such a level that the effluents are of large enough quantity to affect the stratosphere globally. These effluents must be measured and their effects on the stratosphere quantified.

As in the previous investigations, global remote sensing of the atmosphere both from low Earth orbit and geosynchronous orbit combined with simultaneous observation of solar and magnetospheric energy inputs will hold the key to understanding stratospheric processes.

III. CHARACTERISTICS OF A SOLAR-TERRESTRIAL OBSERVATORY

A. Approach

Operation of an effective Solar-Terrestrial Observatory will depend on our capability to make comprehensive simultaneous measurements using *in situ*, remote-sensing, and active probing techniques. These measurements should be made continuously or with sufficient frequency over time scales adequate to record the diurnal, solar rotational, seasonal, and solar-cycle variations which are thought to hold the key to our understanding of many of the important solar-terrestrial interaction mechanisms.

The needed measurements and investigations, outlined in the previous sections, place certain general and specific requirements on the platform to be used, on its orbit, and on its complement of instruments. The following paragraphs outline a number of these requirements as presently envisioned.

B. Orbit

Low-altitude orbits are well suited for many of the required monitoring and experimental operations. Initial operations (for example, solar observations) could begin at any inclination. For studies of the energy input to the atmosphere resulting from magnetospheric activity and solar-flare protons, a high-inclination orbit ($> 65°$) is preferable. Certain magnetospheric and atmospheric investigations can be conducted from a lower ($< 58°$) inclination orbit, but their scope is limited. Second-generation observations at geosynchronous orbit would be extremely useful for in situ measurements of magnetospheric energy transport processes combined with continuous remote-sensing observations of the Sun and an entire atmospheric hemisphere.

This pattern of orbital requirements is quite compatible with an evolutionary sequence envisioned for Space Station development. If a low-altitude station were maintained as a way station to a geosynchronous station, a Solar-Terrestrial Observatory could productively be a module in both.

C. Platform Characteristics

Provisions must be available for the pointing of individual instruments independently of Space Station attitude. The observing requirements will include cryogenically cooled instruments and large instrument arrays. These must be pointed at the Sun, at selected solar features, at selected atmospheric locations (including limb scanning), and simultaneously up and down magnetic field lines. Pointing requirements will vary from a fraction of an arc second for some of the solar instruments, through $0.1°$ for selected atmospheric remote-sensing instruments and electric or magnetic field detectors, to $1°$ for the magnetospheric particle detectors.

The observatory should be equipped with a data processing facility capable of reducing data from onboard instruments and combining it with real-time data from supporting subsatellites and the ground. In-orbit laboratory facilities are required for the testing and possible modification of selected onboard instruments, including optical systems. An EVA capability would be extremely useful in the repair and maintenance of instruments.

D. Manned Operation

Operation of the Space Station observatory would be optimized in many respects by a manned facility. The use of a properly trained onboard scientist is expected to be quite cost effective in the performance of active probing experiments using man's superior pattern recognition capability and ability to respond to the unexpected. In the remote-sensing and direct-measurement operations, a man-in-the-loop concept is also expected to add significantly to the versatility of the observatory and to the optimization of its observing capabilities. He would be able to accomplish onboard calibration, repair, maintenance, and instrument improvement as well as data processing and analysis.

The large coordinated observing programs involving observation of specific cause-and-effect links between Sun and Earth will be greatly enhanced by manned operation, with the onboard scientist examining the results and then configuring and carrying out the follow-on experiment. Although the Solar-Terrestrial Observatory experiments will be enhanced by man's presence, they will not necessarily require continuous manned operation because many of the observations can be carried out in a semi-automated fashion.

E. Duration of Observations

Long-duration operations are essential in order to study and monitor the diurnal, solar rotational, seasonal, and solar-cycle variations that are important aspects of solar-terrestrial interactions. Realization of an effective program of long duration requires the ability to calibrate, repair, maintain, and upgrade the onboard instrumentation to as great a degree as possible.

F. Subsatellite Clusters or Ensembles

A number of the anticipated instruments will be large and massive because of cryogenic cooling, substantial energy storage requirements, and optical systems complexity. These instruments will require the accommodations of a Space Station module and exposed platform. On the other hand, other instruments, while much smaller, will require freedom from electromagnetic and chemical contamination, and perhaps direct access to rather remote regions of the magnetosphere or to the solar wind.

It is anticipated, then, that accomplishment of the objective of a Solar-Terrestrial Observatory will require a cluster or ensemble of small subsatellites able to transmit data directly back to the main observatory. An example of this operation would consist of a subsatellite in heliocentric orbit monitoring the solar-wind variations, with another satellite in the magnetosphere near the observatory monitoring ambient plasma conditions outside the disturbed electromagnetic environment of the large Space Station. Information from these subsatellites would be telemetered to the observatory.

G. Instrumentation

In order to make the comprehensive simultaneous set of measurements required for the solar, magnetospheric, and atmospheric observations, a large observatory is visualized. A modular approach in which instruments with similar pointing, power, thermal, and data handling requirements are grouped in various combinations may facilitate the overall integration and operation of the observatory.

The instrumentation consists of three major categories: remote sensing, active probing, and passive *in situ* diagnostics. The study of solar processes will be done with remote sensing techniques which have evolved out of the Skylab missions. Remote sensing will also be used to sound the Earth's atmosphere for concentrations, temperatures, and winds. The active experimentation, consisting of particle accelerators, transmitters, laser radar systems, and gas release mechanisms, will seek to probe the magnetosphere and atmosphere around the observatory and measure the response of the system. The passive *in situ* diagnostic instruments will constantly monitor the state of the magnetosphere and will provide the background information needed to conduct the active experiments.

All of these instrument and experiment techniques can be developed on the short-duration sortie mode flights of the Spacelab/Shuttle. Their application to probing solar, magnetospheric, and atmospheric processes will be well proven for long-duration use in the Solar-Terrestrial Observatory.

IV. CONCLUSIONS

The evidence is overwhelming that the solar-terrestrial environment is a dynamic, tightly coupled, interactive system in which variable solar energy is transmitted through electromagnetic radiation and the solar wind to the Earth's magnetosphere and atmosphere. The constantly changing solar input coupled with the continuous redistribution of energy near the Earth constitute the external boundary conditions which determine the characteristics of our global environment.

An understanding and subsequent management of this environment will require a well-planned, coordinated set of observations of solar processes and the accompanying magnetospheric and atmospheric responses. A major element in this observational plan should be a Solar-Terrestrial Observatory module of a manned Space Station which would be operational initially in a low Earth orbit with a follow-on mode at geosynchronous orbit. The Solar-Terrestrial Observatory would be a self-contained module and exposed platform facility which includes a variety of remote sensing, active probing, and passive diagnostic instrumentation. It would also include a computer facility capable of interrogating and processing information from several subsatellites located in the magnetosphere and the solar wind. The manned activities would center around the conduct of coordinated experiments, repair and calibration of the instruments, and onboard analysis of the experimental data. The highly trained scientist participation will insure a flexible and evolutionary operation of the observatory.

The mode of operation of the Solar-Terrestrial Observatory would change with time. Initially it would focus upon filling in the missing pieces in a working understanding of the solar-terrestrial environment. Ultimately it would reach an operational phase in support of useful predictions and forecasts for numerous environmental factors. The mature operational phase would utilize an observational mode that adapts to circumstances as they occur, in contrast to a purely monitoring mode. As in the case of present hurricane tracking, the Solar-Terrestrial Observatory would, for example, adapt its observations to follow the course of events of a major solar flare and its impact on the Earth. This capability distinguishes the observatory as an appropriate element of a permanent manned Space Station.

In the operational phase, the list of factors worth predicting grows with the climbing complexity of civilization. Already many examples can be cited. Agriculture, from the grass-roots farmer to the senior government official, requires reliable short-term weather predictions and long-term climate forecasts. Lawmakers require a knowledge of the effects of man-made pollutants on the atmosphere to provide a basis for protective legislation. Communication activities need warnings of ionospheric disturbances. Electrical power distributors must be made aware that coming magnetic storms may induce currents that will throw circuit breakers throughout their networks. Prospectors for mineral resources can benefit from a preknowledge of periods of magnetic quiescence propitious for magnetic prospecting. Air and sea transportation can save substantial monies and precious fuel if they can schedule their trips in accord with meteorological expectations.

All of the previous examples are real in the sense that they are being done now in the restricted ways that are possible with our limited knowledge of the solar-terrestrial environment. Much more can and must be done in the complex civilization of our future.

The concept of Earth as a spaceship has gained recognition in recent years. Thanks to the space program, it is an image which is readily appreciated, connoting as it does an object with limited resources and an environment with limited capability. Unfortunately, the analogy is becoming increasingly apt as the world population grows inexorably and as developing nations, which are striving for some form of quality-of-life parity with their wealthier neighbors, increase per capita consumption of both energy and raw materials. This two-pronged forcing function is pushing us toward limits of natural resources and limits of the ability of the environment to cleanse and renew itself. This nation cannot control world population nor the aspirations of developing nations. It can, however, determine the limits of the life support system and how it can be managed for optimal effect. In the past this was neither possible nor necessary; the scale of human impact was far below the scale of global resources. To date we have experienced only the initial ripples of the economic consequences of approaching global limits of natural resources and only isolated instances of the physical limits of our environment. For the future, ignorance will be a luxury we cannot afford, and knowledge a requisite for survival.

The Solar-Terrestrial Observatory, with its long-duration manned mission and simultaneous measurement of the relationship between solar activity changes and terrestrial response, will provide us with the insight and understanding necessary to model and predict changes in our complex but delicate environmental system. It will allow us to more fully understand our Sun-Earth system. It will place man in a better position from which to manage his environment, to plan the use of his resources, and, in short, to control his destiny on this planet.

APPROVAL

NASA WORKSHOP ON SOLAR-TERRESTRIAL STUDIES
FROM A MANNED SPACE STATION

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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